THE OUTLINE OF KNOWLEDGE

EDITED BY

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BOTANY

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ASTRONOMY

BY WALDEMAR KAEMPFFERT AND HERBERT T. WADE

INTRODUCTION BY E. E. BARNARD

ATOMS, MOLECULES, AND ELECTRONS

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ANTHROPOLOGY

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CHEMISTRY

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CHAPTER I

EARLY DEVELOPMENT

"WHAT is the content and scope of the science of botany?" asks Prof. Herbert Maule Richards, in a recent lecture, and his reply is very true. "Popular opinion," he says, "will answer somewhat easily: Botany consists in the gathering of plants, and the dismembering of them, in connection with the use of a complicated terminology. That is the beginning and end of botany as it is understood by the majority; there is nothing more to be said. In consequence, the employment of the botanist seems so trivial, so very remote from important human interests that no second thought is given to it. The conception formed in ignorance is continued in ignorance. Even the zoologist is at an advantage, for the public is finally forced to admit that it does not know what he is about, while it understands the botanist very well. He is quite hopeless, for, while flowers may be pretty things to pick, they should not be pulled to pieces, and if he does not happen to be interested in dissecting flowers he is not a botanist but simply a fraud.

"Under botany we have to consider all the questions as to the form, functions, the classification and the distribution of those organisms that are called plants. In the beginning all that was known about plants might be readily comprehended under the simple caption, Botany, but in modern times the rapid accumulation of facts has demanded a segregation of different lines of work. Thus have arisen the divisions of botanical activity, which, for our purposes, may be classed under three heads. First, the taxonomic, or as more commonly called, the systematic side, which has to do with the classification, mainly as established by gross morphology. Second, the morphology field which concerns itself with the outward and inward form and structure and the development thereof, which may or may not have direct relation with taxonomic work. Third, there is the domain of physiology which treats of function.

"Any folk which had so far emerged from the stage of savagery as to stop to notice the world about it would perforce pay some at-

tention to plants. A discrimination of the medicinal uses of plants is often noticeable even in primitive peoples, and with such observation goes also the discrimination of difference in form, the prototype of morphological research.

"In our own civilization we can trace back the history of botany to Aristotle, who affords us some record of the plant forms known at his time, tho the influence which his philosophy wielded, even down to the middle of the last century, was of vastly greater importance than any contribution which he made to botany itself. Theophrastus gave a fuller account of plants, and later came the inquiring and ever curious Pliny. Dioscorides, however, in the first or second century of our era, was one of the first to investigate plants with any attempt at thoroness even from the standpoint of the knowledge of the time. As is shown especially in Dioscorides' work, the study of plants was largely from their use as drugs, and they were described simply to facilitate their recognition. Any real knowledge of them was naturally meager, and false ideas that clung for a long time, some until comparatively recently, prevented any proper conception of form and function.

"The contributions become of less and less value as we approach the middle ages, the botanical writings of which time were full of the wildest fantasy and superstition. In the sixteenth century in northern Europe, particularly Germany, there was a movement toward the real study of plants from the plants themselves as evidenced by the works of the herbalists, but no attempt at classification was made. Here there was an attempt at the enumeration and illustration of plants from living specimens, and confused and empirical as this work was, it was actuated by an honest endeavor to record, as accurately as possible, actual forms, and not fanciful abstractions which never did and never could have existed. All the descriptions were detached from one another and little or no attempt was made at classification, tho by the repeated study of many similar forms the idea of natural relationship began to dawn in a vague way. The actual purpose of all this plant study was the recording of the official plants, for special knowledge of plants was still confined to their uses in medicine.

"While this movement was advancing in northern Europe, a mainly artificial system of classification was developing in Italy and found its culmination in the work of Cæsalpino, who strongly influenced the progress of botany, even after his own time and into the middle of the eighteenth century."

"As the nature of plants," so begins Cæsalpino's book, "possesses only that kind of soul by which they are nourished, grow, and produce their like, and they are therefore without sensation and motion in which the nature of animals consists, plants have accordingly need

of a much smaller apparatus of organs than animals." This idea reappears again and again in the history of botany, and the anatomists and physiologists of the eighteenth century were never weary of dilating on the simplicity of the structure of plants and of the functions of their organs. "But since the function of the nutritive soul consists in producing something like itself, and this like has its origin in the food for maintaining the life of the individual, or in the seed for continuing the species, perfect plants have at most two parts, which are, however, of the highest necessity; one part called the root by which they procure food; the other by which they bear the fruit."

This conception of the upright stem as the seed-bearer of the plant, which is in the main correct, also was long maintained in botany. It should be observed also that the production of the seed is spoken of as merely another kind of nutrition, a notion which afterward prevented Malpighi from correctly explaining the flower and fruit, and in a modified form led Kaspar Friedrich Wolff in 1759 to a very wrong conception of the nature of the sexual function. The next sentence in Cæsalpino leads into the heart of the Aristotelian misinterpretation of the plant, according to which the root answers to the mouth or stomach, and must therefore be regarded in idea as the upper part altho it is the lower in position, and the plant would have to be compared with an animal set on its head, and the upper and lower parts determined accordingly.

Cæsalpino's discussion of the seat of the soul in plants is of special interest in connection with certain views of later botanists. "Whether any one part in plants can be assigned as the seat of the soul, such as the heart in animals, is a matter for consideration," he says, "for since the soul is the active principle ('actus') of the organic body, it can neither be 'tota in toto' nor 'tota in singulis partibus,' but entirely in some one and chief part, from which life is distributed to the other dependent parts. If the function of the root is to draw food from the earth, and of the stem to bear the seeds, and the two cannot exchange functions, so that the root should bear seeds and the shoot penetrate into the earth, there must either be two souls different in kind and separate in place, the one residing in the root, the other in the shoot, or there must be only one, which supplies both with their peculiar capabilities."

"It may be remarked here," says Julius von Sachs in his "History of Botany," "that the point of union between the root and the stem, in which Cæsalpino placed the seat of the plant-soul, afterward received the name of root-neck (collet); and tho the Linnæan botanists of the nineteenth century were unaware of what Cæsalpino had proved in the sixteenth, and did not even believe in a soul of plants, they still entertained a superstitious respect for this part of the plant,

which is really no part at all; and this, it would seem, explains the fact that an importance scarcely intelligible without reference to history was once attributed to it, especially by some French botanists."

The theoretical introduction to his excellent and copious remarks on the parts of fructification may supply another example of Cæsalpino's peripatetic method: "As the final cause, 'finis,' of plants consists in that propagation which is effected by the seed, while propagation from a shoot is of a more imperfect nature, in so far as plants do exist in a divided state, so the beauty of plants is best shown in the production of seed, for in the number of the parts and the forms and varieties of the seed-vessels the fructification shows a much greater amount of adornment than the unfolding of a shoot; this wonderful beauty proves the delight, 'delitas,' of generating nature in the bringing forth of seeds. Consequently as in animals the seed is an excretion of the most highly refined food-substance in the heart, by the vital warmth and spirit of which it is made fruitful, so also in plants it is necessary that the substance of the seeds should be secreted from the part in which the principle of the natural heat lies, and this part is the pith. For this reason, therefore, the pith of the seed (that is, the substance of the cotyledons and of the endosperm) springs from the moister and purer part of the food, while the husk which surrounds the seed for protection springs from the coarser part. It was unnecessary to separate a special fertilizing substance from the rest of the matter in plants, as it is separated in animals which are thus distinguished as male and female."

This last remark and some lengthy deductions which follow are intended to prove, after the example of Aristotle, the absence and indeed the impossibility of sexuality in plants, and accordingly Cæsalpino goes on to compare the parts of the flower, which he knew better than his contemporaries, with the envelopes of the ova in the fetus of animals, which he regards as organs of protection.

"The doctrine of metamorphosis," suggests Von Sachs, "appears in a more consistent and necessary form in Cæsalpino than in the botanists of the nineteenth century before Darwin; it flows more immediately from his philosophical views on the nature of plants, and appears therefore up to a certain point thoroly intelligible. We see in Cæsalpino's doctrine of metamorphosis without doubt the theory of the flower afterward adopted by Linnæus, tho in a somewhat different form." That Linnæus himself regarded the theory ascribed to him on the nature of the flower as the opinion of Cæsalpino also, is shown in his "Classes Plantarum," where in describing Cæsalpino's system he says: "He regarded the flower as the interior portions of the plant, which emerge from the bursting rind; the calyx as a thicker portion of the rind of the shoot; the corolla as an inner and

thinner rind; the stamens as the interior fibers of the wood, and the pistil as the pith of the plant."

But, to do Cæsalpino justice, it would be necessary to give a full account of his very numerous, accurate and often acute observations on the position of leaves, the formation of fruits, the distribution of seeds and their position in the fruit, of his comparative observations on the parts of the fruit in different plants, and above all of his very excellent description of plants with tendrils and climbing plants, of those that are armed with thorns and the like. Tho there is naturally much that is erroneous and inexact in his accounts, yet in the chapters on these subjects may be seen the first beginning of a comparative morphology, which quite casts into the shade all that Aristotle and Theophrastus have said on the subject. But the most brilliant portions of his general botany are those in which he gives the outlines of his views on the systematic arrangement of plants.

All that Cæsalpino says on systematic arrangement shows that he was perfectly clear in his own mind with regard to the distinction between a division on subjective grounds, and one that respects the inner nature of plants themselves, and that he accepted the latter as the only true one. He says, for instance: "We seek out similarities and dissimilarities of form, in which the essence, 'substantia,' of plants consists, but not of things which are merely accidents of them, 'quæ accidunt ipsis.'" Medical virtues and other useful qualities are, he says, just such accidents. Here the path is opened, along which all scientific arrangement must proceed, if it is to exhibit real natural affinities, but at the same time there is a warning already of the error which beset systematic botany up to Darwin's time; if in the above sentence be substituted the word idea for that of substance, and the two expressions have much the same meaning in the Aristotelian and Platonic view of nature, there will be recognized the modern pre-Darwinian doctrine, that species, genera, and families represent "ideam quandam" and "quoddam supranaturale."

The next great figure in botanical science was Joachim Jung. He was born in Lübeck in the year 1587, and died after an eventful life in 1657. He was a contemporary of Kepler, Galileo, Vesal, Bacon, Gassendi, and Descartes. After having been already a professor in Giessen, he applied himself to the study of medicine in Rostock, was in Padua in 1618 and 1619, and there, as may confidently be believed, became acquainted with the botanical doctrines of Cæsalpino, who had died fifteen years before. He occupied himself with the philosophy of the day, in which he appeared as an opponent of scholasticism and of Aristotle, and also with various branches of science, mathematics, physics, mineralogy, zoology, and botany. In 1662 his pupil, Martin Fogel, printed the "Doxoscopiæ Physicæ Minores," a work of enormous compass left in manuscript

at the master's death, and another pupil, Johann Vagetius, the "Isagoge Phytoscopica," in 1678. Ray, however, states that a copy of notes on botanical subjects had already reached England in 1660. He was the first who objected to the traditional division of plants into trees and herbs as not founded on their true nature. But how firmly this old dogma was established is well shown by the fact that Ray at the end of the century still retained this division, tho he founded his botanical theories on the "Isagoge" of Jung. Jung was in advance of Cæsalpino and his own contemporaries in repeatedly expressing his doubt of the existence of spontaneous generation.

"The 'Isagoge Phytoscopica,' a system of theoretical botany," says Von Sachs, "very concisely written and in the form of propositions arranged in strict logical sequence, was a more important work and had more lasting effects upon the history of botany. The first chapter of the 'Isagoge' discusses the distinction between plants and animals. A plant is, according to Jung, a living but not a sentient body; or it is a body attached to a fixed spot or a fixed substratum, from which it can obtain immediate nourishment, grow and propagate itself. A plant feeds when it transforms the nourishment which it takes up into the substance of its parts, in order to replace what has been dissipated by its natural heat and interior fire. A plant grows when it adds more substance than has been dissipated, and thus becomes larger and forms new parts. The growth of plants is distinguished from that of animals by the circumstance that their parts are not all growing at the same time, for leaves and shoots cease to grow as soon as they arrive at maturity; but then new leaves, shoots, and flowers are produced. A plant is said to propagate itself when it produces another specifically like itself; this is the idea in its broader acceptation. We see that here, as in Cæsalpino, the idea of the species is connected with that of propagation.

"The second chapter, headed 'Plantæ Partitio,' treats of the most important morphological relations in the external differentiation of plants; here Jung adheres essentially to Cæsalpino's view, that the whole body in all plants, except the lowest forms, is composed of two chief parts, the root as the organ which takes up the food, and the stem above the ground which bears the fructification. Jung's theory of the flower suffers, as in Cæsalpino, from his entire ignorance of the difference of sexes in plants, which is sufficient to render any satisfactory definition of the idea of a flower impossible."

While Cæsalpino, Kaspar Bauhin, and Jung stand as solitary forms each in his own generation, the last thirty years of the seventeenth century are marked by the stirring activity of a number of contemporary botanists. While during this period physics were making rapid advances in the hands of Newton, philosophy in those of Locke and Leibnitz, and the anatomy and physiology of plants by the labors

of Malpighi and Grew, systematic botany was also being developed, tho by no means to the same extent or with equally profound results, by Morison, Ray, Bachmann (Rivinus), and Tournefort. The works of these men and of their less gifted adherents, following rapidly upon or partly synchronous with each other, led to an exchange of opinions and sometimes to polemical discussion, such as had not before arisen on botanical subjects; this abundance of literature, with the increased animation of its style, excited a more permanent interest, which spread beyond the narrow circle of the professional adepts.

Carl Linnæus, called Carl von Linné after 1757, was born in 1707 at Rashult in Sweden, where his father was preacher. Linnæus is commonly regarded as the reformer of the natural sciences which are distinguished by the term descriptive, and it is usual to say that a new epoch in the history of our science begins with him, as a new astronomy began with Copernicus and new physics with Galileo. "This conception of Linnæus' historical position," Von Sachs points out, "as far at least as his chief subject, botany, is concerned, can only be entertained by one who is not acquainted with the works of Cæsalpino, Jung, Ray and Bachmann, or who disregards the numerous quotations from them in Linnæus' theoretical writings. On the contrary, Linnæus is preëminently the last link in the chain of development represented by the above-named writers; the field of view and the ideas of Linnæus are substantially the same as theirs; he shares with them in the fundamental errors of the time, and indeed essentially contributed to transmit them to the nineteenth century. But to maintain that Linnæus marks not the beginning of a new epoch, but the conclusion of an old one, does not at all imply that his labors had no influence upon the time that followed him."

If the works of the earlier botanists are compared with Linnæus' "Fundamenta Botanica" (1736), his "Classes Plantarum" (1738) and his "Philosophia Botanica" (1751), it becomes evident that the ideas on which his theories are based are to be found scattered up and down in the works of his predecessors. Further, whoever has traced the history of the sexual theory from the time of Cameraraius (1694), must allow that Linnæus added nothing new to it, tho he contributed essentially to its recognition. But that which gave Linnæus so overwhelming an importance for his own time was the skilful way in which he gathered up all that had been done before him; this fusing together of the scattered acquisitions of the past is the great and characteristic merit of Linnæus.

Cæsalpino was the first who introduced Aristotelian modes of thought into botany; his system was intended to be a natural one, but it was in reality extremely unnatural; Linnæus, in whose works the profound impression which he had received from Cæsalpino is

everywhere to be traced, retained all that was important in his predecessor's views, but perceived at the same time what no one before him had perceived, that the method pursued by Cæsalpino could never do justice to those natural affinities which it was his object to discover, and that in this way only an artificial tho very serviceable arrangement could be attained, while the exhibition of natural affinities must be sought by other means.

As regards the terminology of the parts of plants, which was all that the morphology of the day attempted, Linnæus simply adopted all that was contained in the "Isagoge" of Jung, but gave it a more perspicuous form, and advanced the theory of the flower by accepting without hesitation the sexual importance of the stamens, which was still but little attended to; he thus arrived at a better general conception of the flower, and this bore fruit again in a terminology which is as clear as it is convenient. But there was one great misconception in the matter, which has not a little contributed to increase Linnæus' reputation. He called his artificial system, founded on the number, union and grouping of the stamens and carpels, the sexual system of plants, because he rested its supposed superiority on the fact that it was founded upon organs the function of which lays claim to the very highest importance. But it is obvious that the sexual system of Linnæus would have the same value for the purposes of classification, if the stamens had nothing whatever to do with propagation, or if their sexual significance were quite unknown. For it is exactly those characters of the stamens which Linnæus employs for purposes of classification, their number and mode of union, which are matters of entire indifference as regards the sexual function.

Linnæus distinctly declared it was his view that the highest and only worthy task of a botanist was to know all species of the vegetable kingdom exactly by name, and his school in Germany and England adhered to it so firmly that it established itself with the general public, who to the present day consider it as a self-evident proposition that a botanist exists essentially for the purpose of at once designating any and every plant by a name. Like his predecessors, Linnæus regarded morphology and general theoretical botany only as means to be used for discovering the principles of terminology and definition, with a view to the improvement of the art of describing plants.

"The most pernicious feature in scholasticism and the Aristotelian philosophy is the confounding of mere conceptions and words with the objective reality of the things denoted by them," says Von Sachs upon this point. "Men took a special pleasure in deducing the nature of things from the original meaning of the words, and even the question of the existence or non-existence of a thing was answered

from the idea of it. This way of thinking is found everywhere in Linnæus, not only where he is busy as systematist and describer, but where he wishes to give information on the nature of plants and the phenomena of their life. Linnæus cared little for experimental proof; he expends all his art on a genuine scholastic demonstration intended to prove the existence of sexuality as arising necessarily from the nature of the plant."

On the whole the superiority of Linnæus lay in his natural gift for discriminating and classifying the objects which engaged his attention; he might almost be said to have been a classifying, coordinating and subordinating machine. He dealt with all about which he wrote in the way in which he dealt with objects of natural history.

"In any attempt to estimate the advance which the science owes to the labors of Linnæus," says the former writer, "the chief prominence must be assigned to two points: First to his success in carrying out the binary nomenclature in connection with the careful and methodical study which he bestowed on the distinguishing of genera and species; this system of nomenclature he endeavored to extend to the whole of the then known vegetable world, and thus descriptive botany in its narrower sense assumed through his instrumentality an entirely new form. The second merit is that while he framed his artificial sexual system, he exhibited a fragment of a natural system by its side and repeatedly declared that the chief task of botanists is to discover the natural system. Thus he cleared the ground for systematic botany."

The main features of Linnæus' theoretical botany can best be learned from the "Philosophia Botanica," which may be regarded as a text-book of that which Linnæus called botany and which far surpasses all earlier compositions of the kind in perspicuity and precision and in copiousness of material, and indeed it would be difficult to find in the ninety years after 1781 a text-book of botany which treats what was known on the subject at each period with equal clearness and completeness. The vegetable world, says Linnæus, comprises seven families, Fungi, Algæ, Mosses, Ferns, Grasses, Palms and Plants. All are composed of three kinds of vessels, sap-vessels which convey the fluids, tubes which store up the sap in their cavities and tracheæ which take in air; these statements Linnæus adopts from Malpighi and Grew.

The parts in the individual plant which the beginner must distinguish are three: the root, the herb and the parts of fructification, in which enumeration Linnæus departs from his predecessors, by whom the fructification and the herb together are opposed to the root. In the central part of the plant is the pith, enclosed by the wood which is formed from the bast; the bast is distinct from the rind, which again is covered by the epidermis; these anatomical facts are from

Malpighi; the statement that the pith grows by extending itself and its enevelopes is borrowed from Marionette.

The root, which takes up the food, and produces the stem and the fructification, consists of pith, wood, bast and rind, and is divided into the two parts, "caudex" and "radicula." The "caudex" answers pretty nearly to the modern primary root and rhizomes, the "radicula" to what is now called secondary roots. The herb springs from the root and is terminated by the fructification; it consists of the stem, leaves, leaf-supports ("fulcrum") and the organs of hiberation ("hibernaculum"). Then follow the further distinctions of stem and leaves, the terminology, still partly in use and resting essentially on the definitions of Jung, is here set forth in great detail. Linnæus, however, does not mention the remarkable distinction between stem and leaf which Jung founded on relations of symmetry. In this course of mixing up morphological and biological relations of organs he was followed by botanists till late into the nineteenth century.

Linnæus goes far beyond his predecessors in distinguishing and naming the organs of fructification. The fructification, he says, is a temporary part in plants devoted to propagation, terminating the old and beginning the new. He distinguishes the following seven parts: (1) The calyx, which represents the rind, including in this term the involucre of the Umbelliferæ, the spathe, the calyptra of Mosses and even the volva of certain Fungi, another instance of the way in which Linnæus was guided by external appearance in his terminology of the parts of plants; (2) the corolla, which represents the inner rind (bast) of the plant; (3) the stamen, which produces the pollen; (4) the pistil, which is attached to the fruit and receives the pollen; here for the first time the ovary, style and stigma are clearly distinguished. But next comes as a special organ (5) the pericarp, the ovary which contains the seed. Nevertheless Linnæus distinguishes the different forms of fruit much better than his predecessors had done. (6) The seed is a part of the plant that falls off from it, the rudiment of a new plant, and it is excited to active life by the pollen. The treatment of the seed and its parts is the feeblest of all Linnæus' efforts; he follows Cæsalpino, but his account of the parts of the seed is much more imperfect than that of Cæsalpino and his successors. (7) By the word "receptaculum" he understands everything by which the parts of the fructification are connected together, both the "receptaculum proprium," which unites the parts of the single flower, and the "receptaculum commune," under which term he comprises the most diverse forms of inflorescence (umbel, cyme, spadix).

He concludes with the remark that the essence of the flower consists in the anther and the stigma, that of the fruit in the seed, that

of the fructification in the flower and the fruit and that of all vegetable forms in the fructification, and he adds a long list of distinctions between the organs of fructification with their names; among these organs appear the nectaries, which he was the first to distinguish.

From Linnæus the advance was more rapid, and, while most of the study in plants centered on the work of classification, there were unmistakable signs of other interests. The ideas of the classifiers were still hampered by the dogma of the constancy of species, which continually clashed with the insistent and undeniable evidences of the genetic relationships of organic forms. Despite the movement in favor of the idea of the development of species from previously existing forms, despite the views advanced by Lamarck and others at about that time, despite, indeed, the more strictly botanical investigations in the morphological field which were brought forward during the first half of the nineteenth century—despite all these things, the botanist was unable to break away from the concept of groups of plants as abstract ideas.

It was not until 1859 that the publication of Darwin's "Origin of Species" drove biologists to a different point of view. Then the rational idea of the evolution of organic forms explained in a similar rational fashion the observed genetic relationships of groups of plants. "No longer," says Richards, "did the classifier hesitatingly admit the possibility of the evolution of species and deny that of genera and higher groups, no longer did he maintain his artificial groups, which had no more relation to each other than successive throws of dice, but he admitted the whole great scheme implied by the evolution of organic forms from preëxisting types."

"The natural system was rightly appreciated by Linnæus," says Asa Gray in his "Structural Botany," "who pronounced it to be the first and last desideratum in systematic botany; and he early attempted to collocate most known genera under natural orders, but without definition or arrangement. In his later years he was unable to accomplish anything more." The difficult problem was taken up by Linnæus' contemporary and correspondent, Bernard de Jussieu. His pupil, Adanson, published in 1763, in his "Familles des Plantes," the first complete system of natural orders. Adanson himself thus defines his idea of species: "The moderns define a species of plant as a collection of several individuals which resemble each other perfectly, yet not in everything, but in the essential parts and qualities, without, however, giving attention to the differences caused in these individuals either by sex or accidental varieties.

Antoine Laurent de Jussieu, nephew of Bernard, followed Andanson. "He has been called the founder of the natural system of Botany," says Asa Gray, "and to him more than to any other person

this honor may be ascribed. In his 'Genera Plantarum secundum Ordines Naturales disposita,' 1789, natural orders of plants, one hundred in number, were first established and defined by proper characters, and nearly all known genera arranged under them."

The next great systematist was Auguste Pyrame de Candolle. Reversing the order of Jussieu, who proceeded from the lower or simpler to the higher or more complex forms, De Candolle began with the latter, the phenogamous or flowering plants, and with those having typically complete flowers. De Candolle's interest was perhaps more from a morphological point of view, altho he is to be regarded as a systematist, and from that standpoint it will be seen later that his work was of the first importance.

John Lindley in successive attempts (between 1830 and 1845) variously modified and in some few respects improved the Candollean arrangement. Robert Brown, next to Jussieu, did more than any other botanist for the proper establishment and correct characterization of the natural orders. Stephen Ladislaus Endlicer, of Vienna, a contemporary of Lindley, of less botanical genius but of great erudition and aptness for classification, brought out his complete "Genera Plantarum secundum Ordines Naturales disposita" between the years 1836 and 1840. The "Genera Plantarum" of Bentham and Hooker adopts in a general way the Candollean sequence of order with various emendations, divides the class of Dicotyledons into two subclasses, Angiosperms and Gymnosperms, with still further divisions in the Angiosperms.

In this country botanists have to thank the labors of John Torrey and Asa Gray for the firm foundation upon which the knowledge of American flora is built. Of the two, Asa Gray was by far the broader in his interests and is regarded by many as the father of American botany. He had considerable knowledge of other fields than that of mere systematic botany of the higher plants and was perhaps the ablest protagonist whom Darwin had in this country. He wrote numerous papers in defense of the then new theory of the origin of species. His main work, however, was the taxonomic study of the flora of North America.

Discussion of the definition of species, how much a species includes and of what constitutes a variety is at present a foremost question among taxonomists, and the effort seems to look toward simplification and lessening of the numbers already formed. Linnæus tells in his "Philosophia Botanica" (1751): "We enumerate as many species as different forms were originally created." He also says, "There are as many species as the Infinite Being originally produced different forms, and these forms following the laws of reproduction imposed upon them, have produced more, but always to themselves. Therefore

there are as many species as there are different forms or structures met with to-day.

The idea of the species set forth by Lamarck is thus defined: "In botany as in zoology a species is necessarily constituted of the aggregation of similar individuals which perpetuate themselves, the same, by reproduction. I understand similarity in the essential qualities of the species, because the individuals which constitute it offer frequently accidental differences, which give rise to varieties and sometimes sexual differences, which belong, however, to the same species, as the male and female hemp, in which all the individuals constitute the common cultivated hemp. Thus, without the constant reproduction of similar individuals, there could not exist a true species."

De Candolle and Sprengle say that "by species we understand a number of plants which agree with one another in invariable marks. No doubt there were in the preceding state of our globe other species of plants which have now perished and the remains of which we still find in impressions in shale, slate-clay and other floetz rocks. Whether the present species, which often resemble these, have arisen from them; whether the great revolution on the surface of the earth, which we read in the Book of Nature, contributed to these transitions, we know not. What we know is that from as early a time as the human race has left memorials of its existence upon the earth the separate species of plants have maintained the same properties invariably.

"To be sure, we frequently speak of the transitions and crossings of species; and it cannot be denied that something of this kind does not occur, tho without affecting the idea of species which we have proposed. We must, therefore, understand this difference. Species only appear to undergo transitions when we have considered an organ or a property as invariable, which is not so.

"All properties of plants which are subject to change form either a sub-species or a variety. By the former we understand such forms as continue indeed during some reproductions, but at last, by a greater difference of soil, of climate and of treatment, are either lost or changed." John Lindley in his "Introduction to Botany" defines species as "a union of individuals agreeing with each other in all essential characters of vegetation and fructification, capable of reproduction by seed without change, breeding freely together and producing perfect seed from which a fertile progeny can be reared."

To Asa Gray "species in biological natural history is a chain or series of organisms of which the links or component individuals are parent and offspring. Objectively a species is the totality of beings which have come from one stock, in virtue of that most general fact that likeness is transmitted from parent to progeny.

"The two elements of species are (1) community of origin and

(2) similarity of the component individuals. But the degree of similarity is variable, and the fact of genetic relationship can seldom be established by observation or historical evidence. It is from the likeness that the naturalist ordinarily decides that such and such individuals belong to one species. Still the likeness is a consequence of the genetic relationship, so that the latter is the real foundation of species.

"Varieties are forms of species marked by characters of less fixity or importance than are the species themselves. They may be of all grades of difference from the slightest to the most notable; they abound in free nature, but assume particular importance under domestication and cultivation, under which varations are prone to originate, and desirable ones are preserved, led on to further development and relatively fixed."

Charles Darwin, whose work has done so much to put all natural sciences upon their present basis of experimental observation, does not commit himself to an actual statement. He says that "no one definition has satisfied all naturalists; yet every naturalist knows vaguely what he means when he speaks of a species. The term variety is almost equally difficult to define, but here community of descent is almost universally implied, tho it can rarely be proved."

"All the individual plants which resemble each other sufficiently to make us conclude that they are all or may have been all descended from a common parent" are included in one species by George Bentham. "These individuals may often differ from each other in many striking particulars, such as the color of the flower, size of the leaf, etc., but these particulars are such as experience teaches us are liable to vary in the seedlings raised from one individual. When a large number of the individuals of a species differ from the others in any striking particular, they constitute a variety." Britton and Brown consider that "a species is composed of all the individuals of a kind capable of continuous successive propagation among themselves."

"Nature produces individuals," declares Charles E. Bessey, "and nothing more. She produces them in such countless numbers that we are compelled to sort them into kinds in order that we may be able to carry them in our minds. This sorting is classification-taxonomy. But right here we are in danger of misunderstanding the matter. We do not actually sort out our individuals. We imagine them sorted out. It is only to a very slight extent that the systematic botanist ever actually sorts out individuals.

"So species have no actual existence in nature. They are mental concepts and nothing more. They are conceived in order to save ourselves the labor of thinking in terms of individuals, and they must be so framed that they do save us labor."

"It should be borne in mind," ably summarizes Asa Gray, "that the

natural system of botany is natural only in the constitution of its genera, tribes, orders, etc., and in its grand divisions; that its cohorts and the like are as yet only tentative groupings, and that the putting together of any or all these parts in a system, and especially in a lineal order, necessary as a lineal arrangement is, must needs be largely artificial. So that even the best perfected arrangements must always fail to give of themselves more than an imperfect and considerably distorted reflection of the plan of the vegetable kingdom or even of our knowledge of it."

CHAPTER II

PLANT STRUCTURES

The work of the earliest botanist was given over to two main objects, the classification of species and varieties in a manner that should most readily account for the entire system, and the determination of a true basis for such a taxonomic classification, requiring a somewhat close study of the morphology and the physiology of the plant. The later botanists, beginning mainly from the bases laid down by Linnæus, developed the Science of Botany into a study of no little complexity; and questions arose, of intense interest in themselves, but which took for granted a basic knowledge of these simpler matters of structure and of classification. As it would be difficult to carry the development of botanical thought up to its modern complexity without an assurance that the reader was conversant with the general outline, it is thought wiser to touch on it briefly here.

Plants are differentiated from each other by certain variances of their parts, which again reveal causes deeper still. Wherefore an understanding of the nature of these parts should precede a statement of their differences.

Just as the man has various members, by which he sees, hears, feels, so have the plants several kinds of organs. The advantage of this to the plant becomes plain by using the common illustration of the difference between a tribe of savages and a civilized community. Several kinds of organs in a plant mean to the plant just what division of labor means to the community; it results in better work and more work.

All the work done by plants comes under two heads: nutrition and reproduction. This means that every plant must care for two things, (1) the support of its own body (nutrition), and (2) the production of other plants like itself (reproduction). To the great work of nutrition many kinds of work contribute, and the same is true of reproduction. In a complex plant, therefore, there are certain organs which specially contribute to the work of nutrition and others which are specially concerned with the work of reproduction.

The plant is extremely dependent upon its surroundings, more so because of its lack of locomotion. For example, it must receive material from the outside and get rid of waste material. Therefore, organs

must establish certain definite relations with things outside of themselves before they can work effectively; and these necessary relations are known as life-relations. For example, green leaves are definitely related to light—they cannot do their peculiar work without it; many roots must be related to the soil; certain plants are related to abundant water; some plants, such as parasites, are related to other plants. Each organ, therefore, must become adjusted to a complete set of relations, and a plant with several organs has many delicate adjustments to care for. Three conspicuous organs, root, stem and leaf, are concerned with nutrition; and most of these plants have at some time also another structure, the flower, which is concerned with reproduction.

On examining an ordinary leaf, the blade is seen to consist of a green substance through which a network of veins is distributed. The larger veins that enter the blade send off smaller veinlets that are invisible. This is plainly shown by a skeleton leaf, wherein it appears that the vein system or venation of leaves is exceedingly diverse, altho all forms can be referred to a few general plans.

In some leaves a single very prominent vein known as the midrib runs through the middle of the blade. From this all the minor veins arise as branches, and such a leaf is said to be pinnately veined. In other leaves several large veins (ribs) of equal prominence enter the blade and diverge, each giving rise to smaller branches. Such a leaf is said to be palmately veined. In still other leaves all the visible veins run approximately parrallel from the base of the blade to its apex, such leaves being parallel-veined, as distinct from the two preceding, which are both net-veined.

The upper and the under surface of a leaf is covered by a delicate transparent skin (epidermis), which generally shows no green color. "Examined under the compound microscope," says John M. Coulter, "it is seen to be made up of small units of structure known as cells. Each cell is bounded by a wall, and in the epidermis these cells fit closely together, sometimes dovetailing with one another. Characteristic openings in the epidermis also will be discovered, sometimes in very great numbers. The whole apparatus is known as a stoma. These numerous openings are the stomata, which give passageway into the interior of the leaf, putting the internal cells into communication with the air outside and so facilitating the interchange of gases. The size of these apertures may vary under different conditions.

"Between these two epidermal layers is the mass of green tissue making up the body of the leaf, and known as mesophyll. This comprises cells containing the numerous small green bodies (chloroplasts) that give color to the whole leaf. Usually the mesophyll cells are arranged differently in the upper and lower regions of the horizontal leaf. In the upper region the cells just beneath the epidermis are

elongated at right angles to the surface of the leaf, and stand in close contact, forming the palisade tissue. In the lower region of the leaf the cells are irregular in form, and so loosely arranged as to leave air space between the cells, the whole region forming the spongy tissue. The air spaces communicate with one another, thus forming a labyrinthine system of air chambers throughout the spongy mesophyll. It is into this system of air chambers that the stomata open, and thus what may be called an internal atmosphere is in contact with all the green working cells, and this internal atmosphere is in free communication, through the stomata, with the external atmosphere."

"In general," says G. F. Atkinson, "the function of the foliage leaf as an organ of the plant is five-fold: (1) That of carbon-dioxide assimilation; (2) that of transpiration; (3) that of the synthesis of other organic compounds; (4) that of respiration; (5) that of assimilation proper or the making of new living substances."

The importance of the work of leaves is apparent, but this work cannot be done unless the leaf is exposed to light. This fact explains many things in connection with the position and arrangement of leaves. Leaves must be arranged to receive as much light as possible to help in their work, but too intense light is dangerous; hence the adjustment to light is a delicate one.

If green plants should stop the manufacture of carbohydrates the food supply of the world would soon be exhausted. All other forms of food are derived from carbohydrates in some way, and only green plants can add to the stock that is being drawn upon continually. This means that green plants must manufacture carbohydrates not only for their own use but also for the use of animals, and of plants that are not green. Since leaves are chiefly expansions of green tissue, they are conspicuous in the manufacture of carbohydrates.

It must be remembered that the manufacture goes on wherever there is green tissue, whether it is found in leaves or not. A very conspicuous fact about this manufacture is that it cannot go on unless the green tissue is exposed to light. This explains why leaves are adjusted in so many ways to obtain light.

It also gives name to the process, photosynthesis, the name indicating that the work is done in the presence of light. The process demands that carbohydrates shall be made from raw materials common in nature and easily obtained by plants, and in photosynthesis two such substances are used. One of these is water, which in the plants commonly thought of is absorbed by the roots from the soil. The other substance is carbon dioxide, a gas present in small proportion in the air (really in the form of carbonic acid gas), but one which is being constantly renewed as it is used, so that it is always available. Water is made up of one part of oxygen and two parts of hydrogen, while carbon dioxide consists of two parts of oxygen and

one part of carbon. These are just the elements that enter into the structure of a carbohydrate.

In photosynthesis the elements of water and carbon dioxide are separated, and recombined to form a carbohydrate, and in this process oxygen is a waste product and is given off by the working cells. Therefore, in the sunlight a leaf is absorbing carbon dioxide and giving off oxygen, and this gas exchange is the superficial indication that photosynthesis is going on.

"Such an important organ as the leaf," says Coulter again, "with its delicate active cells necessarily in communication with the air, is exposed to numerous dangers. Conspicuous among these dangers are drought, intense light and cold. Perhaps the most common danger to most plants is an excessive loss of water, and when a drought prevails the problem of checking transpiration is a most serious one. As the leaves are the prominent transpiring organs, the chief methods of protection concern them.

The epidermis may be regarded as an ever-present check against transpiration, for without it the active mesophyll cells would soon lose all their water. In some plants of very dry regions what may be regarded as several epidermal layers appear. The cuticle which is often developed upon the epidermis is one of the best protections against loss of water. It is developed by the exposed walls of the epidermal cells, and being constantly renewed from beneath, it may become very thick and many-layered. In dry regions, or in any much exposed place, the cuticle is a very constant feature of plants.

"In many leaves," remarks Atkinson, "certain of the cells of the epidermis grow out into the form of hairs or scales." They may form only a slightly downy covering or the leaf may be covered by a woolly or feltlike mass so that the epidermis is entirely concealed. In dry or cold regions the hairy covering of leaves is very noticeable, often giving them a brilliant silky white or bronze look.

In dry regions each leaf endeavors to expose as small a surface in proportion to substance to the drying air and intense light. That this reduction in size holds a direct relation to the dry conditions is evident from the fact that the same plant often produces small leaves in a dry region and larger ones in moist conditions. In the case of the cactus, a large group in the dry regions of the Southwest, the leaves have become so much reduced that they are no longer used in photosynthesis, and this process is carried on by the green tissue of the globular, cylindrical, or flattened stems. The rosette habit is a very common method of protection used by small plants growing in exposed situations, as bare rocks and sandy ground. The clustered, overlapping leaves form a very effective arrangement for resisting intense light or drought.

There are leaves which can shift their positions according to their

needs, directing their flat surfaces toward the light, or more or less inclining them. Such leaves have been developed most extensively in the great family to which peas and beans belong, the most conspicuous ones being those of the so-called sensitive plants. The name has been given because the leaves respond to various external influences by changing position with remarkable rapidity. A slight touch, or even jarring, will call forth a response from the leaves, and the sudden application of heat gives striking results.

Insect-devouring plants usually grow in swampy regions, the leaves forming small rosettes upon the ground. In one form of sundew the blade is round and the margin is beset by prominent bristle-like hairs, each with a globular gland at its tip. Shorter gland-bearing hairs are scattered also over the inner surface of the blade. All these glands excrete a clear, sticky fluid, which hangs to them like dewdrops, and which, not being dissipated by sunlight, has suggested the name sundew. If a small insect becomes entangled in one of the sticky drops the hair begins to curve inward, and presently presses its victim down upon the surface of the blade. The famous "Venus Flytrap" is found only in certain sandy swamps in North Carolina. The leaf-blade is constructed so as to work like a steel trap, the two halves snapping together, and the marginal bristles interlocking. A few sensitive hairs, like feelers, are developed on the leaf surface, and when one of these is touched by a small flying or hovering insect the trap snaps shut and the insect is caught. Only after digestion, which is a slow process, does the trap open again.

The stem is distinguished as that part of the plant which bears the leaves. "It has for its chief function," says C. C. Curtis, "the production and display of the leaves and roots and the conduction of the materials which these organs are especially concerned in handling. It serves as a connection between them, carrying up the material absorbed by the roots and distributing the various substances received from the leaf." The stem may be compared to a system of transportation carrying building material for new cells and arranging for the bearing away of that which is waste.

The stem best adapted for the proper display of leaves is generally upright, for they can be spread out on all sides and carried upward toward the light. To maintain the erect position is not a simple mechanical problem, and in large, woody stems it involves an extensive development and arrangement of supporting tissues. Other stems lie along the ground bearing leaves only on the free side, while a third great group is that of the climbers, which use other plants as supports. The great lianus of South America belong to this class.

It has been shown that the stem is in a sense a transportation system, and it becomes immediately evident that the material transported

must be largely in soluble form. This liquid is known as sap. "It is important to notice," say J. Y. Bergen and C. M. Davis in their "Principles of Botany," "that sap is by no means the same substance everywhere and at all times. As it first makes its way by osmotic action inward through the root hairs of the growing plant it differs little from ordinary well water. The liquid which flows from the cut stem of a tree just before the buds have begun to burst in the spring is mainly water often with a little dissolved organic acids, proteids and sugar. The sap which is obtained from maple trees in late winter or early spring is far richer in nutritious material, while the elaborated sap which is sent so abundantly into the ear of the corn at the time of its filling out contains great stores of food to support plant or animal life."

Most root-forms are adapted for growth in the soil, but there are many of which this is not true. Thus many of the orchids have aerial roots which fasten the plants to the branch of a tree and absorb moisture from the heavy humid air of a tropical forest; others are adventitious, like the ivy, which cause the plant to cling to a wall; others again, like the mistletoe and the dodder, are parasitic and are adapted to prey upon their host, while another large group of roots is adapted to life in the water, such as the duck-weed.

The length of roots is rarely realized. Thus winter wheat has been found to extend to a depth of seven feet, and the average root stretch of a plant of common oats is 154 feet. The Mexican mesquite has been known to extend sixty feet below ground in the search for water.

The growing tip of each root and rootlet is protected by a cap of cells called the root-cap. This root-cap consists of several layers of cells, the outer ones gradually dying or being worn away as the tip of the root pushes through the soil, and being replaced by new layers which are continually forming beneath.

A short distance behind the root-cap the surface of the root becomes covered by a more or less dense growth of hairs, known as root-hairs. These hairs are outgrowths, sometimes very long ones, from the superficial cells, a single cell producing a single root-hair. In fact, the root-hair is only an extended part of the superficial cell. The root absorbs water and materials dissolved in it from the soil, and the root-hairs enormously increase the absorbing surface. Thousands may occur on a square inch of surface.

In the center of a young root is a solid vascular cylinder, often called the central axis, sometimes enclosing pith. Investing the solid vascular cylinder of the root is the cortex, which often can be stripped from the central axis like a spongy bark.

The wood (xylem) and the bast (phloem) of the vascular cylinder

do not hold the same relation to each other as in the stem. The vascular cylinder, instead of being made up of vascular bundles, with wood toward the center and bast toward the outside, as in stems, is made up of wood and bast strands alternating with each other around the center. The wood strands radiate from the center like the spokes of a wheel, and the bast strands are between these spokes, near their outer ends. This arrangement of wood and bast is peculiar to roots. The vascular bundles of the root connect with those of the stem, and these in turn with those of the leaves, so that throughout the whole plant there is a continuous vascular system.

CHAPTER III

REPRODUCTION STRUCTURES

The root, the stem, and the leaf being the three principal organs in the nutrition of a plant, the matter next of importance is a consideration of the manner of its reproduction. Usually this is popularly supposed to be by a flower, but a large division of plants are flowerless and reproduce in many diverse ways. As, moreover, the mode of reproduction often constitutes a means of differentiating between various species, it will be treated therein, but certain main principles may be laid down.

Thus the earliest form of reproduction is that of mere cell division, which cell, so far as can be seen, is not marked out from other cells; indeed, all the cells are capable of division. Next comes the setting aside of a certain cell which is called a spore; and what seems strange in the vegetable world, certain of these, by the lashing about of filaments, are able to swim, and are called "swimming spores." So far all has been without sex, and is called "ásexual."

But, still very early in the plant kingdom, two cells very like the swimming spores, yet different in action, are produced, which are called "gametes"; these have an affinity for each other, come together, fuse or fertilize, and, thus fertilized, are called "zygospores," and from these are thrown off spores which can produce new plants. These two gametes at first are very similar, but in higher forms become strongly dissimilar, and are called sperms and eggs. The organ producing the sperms is called the "antheridium," that producing the egg is known as the "oögonium," in still higher types the "Archegonium." The last stage in this type of reproductive process is that in which different plants (sometimes different stems) produce sex organs which may be termed respectively male and female. The highest and the vast division of the Plant Kingdom, known as "Spermatophytes," or seed-bearing, is so called because of its development of seeds and reproduction thereby. The gymnosperms, of which pine trees are the best known, produce no flowers, but the Angiosperms have the sexual system very fully developed in the flower.

A flower is a highly modified stem peculiarly adapted for perpetuation. The stem-like nature of the flower is very noticeable before

it opens, at which time a series of leaves protects the delicate parts within. These green leaves are known as the calyx, each leaf of which is separately distinguished as a sepal. "As the bud opens," says Curtis, "a number of organs are disclosed; particularly noticeable are a set of variously colored leaves known as the corolla, each leaf of which is called a petal. Within the perianth (which is the calyx and corolla together are two kinds of organs, the pistils and the stamens, collectively known as sporophylls, since their special work is to produce certain cells called spores." The anthers discharge pollen, which is carried in various ways to the pistil, where the ovules are situated. It is by the fertilization of the female nucleus of the egg-cell at the apex of the embryo sac in the pistil by the male nucleus from a pollen grain that plants arise.

The transfer of the pollen to the pistil.—This transfer—*i.e.*, pollination—is effected in many Angiosperms by insects, altho in some cases the wind serves to carry pollen, as it does in the Gymnosperms. This mutually helpful relation between flowers and insects in some cases has become so intimate that they cannot exist without each other. Flowers are modified in many ways in relation to insect visits, and insects are variously adapted to flowers.

"The pollen," Coulter points out, "may be transferred to the stigma of its own flower, 'self-pollination,' or of some other flower of the same kind, 'cross-pollination.' In the later case the two flowers concerned may be upon the same plant or upon different plants, which may be quite distant from one another. Since flowers are very commonly arranged to secure cross-pollination, it must be more advantageous in general than self-pollination.

"The advantage of this relation to the insect is to secure food. This the flower provides in the form of either nectar or pollen; and insects visiting flowers may be grouped as nectar-feeders, represented by moths and butterflies, and pollen-feeders, represented by the numerous bees and wasps. The presence of these supplies of food in the flower is made known to the insect by the display of color, by odor, or by form. Moreover, the flower not only must secure the visits of suitable insects but also must guard against the depredations of unsuitable ones."

Cross-pollinating flowers may be illustrated under three heads, distinguished from one another by their methods of hindering self-pollination; but it must be understood that almost every kind of flower has its own way of solving the problems of pollination. The following illustration will serve to show one of the processes, that dependent upon position. In this case the pollen and the stigma are ready at the same time, but their position in reference to each other, or in reference to some conformation of the flower, makes it unlikely that the pollen will fall upon the stigma.

In the family Leguminosa, to which the pea, bean, etc., belong, the several stamens and the single carpel are in a cluster enclosed in a boat-shaped structure, "keel," formed by two of the petals. The stigma is at the summit of the style and projects somewhat beyond the pollen sacs, some of whose pollen lodges on a hairy zone on the style below the stigma. While the stigma is not altogether secure from receiving some pollen, the position does not favor it. The projecting keel is the natural landing place for a bee visiting the flower; and it is so inserted that the weight of the insect depresses it and the stigma comes in contact with its body. Not only does the stigma strike the body, but by the glancing blow the surface of the style is rubbed against the insect; and upon this style, below the stigma, the pollen has been shed, and is rubbed off against the insect. At the next flower visited the stigma is likely to strike the pollen obtained from the previous flower, and the style will deposit a new supply of pollen.

But in the general flower, as visited by the insect, the pollen grains that reach the stigma, the specially prepared surface for receiving them, begin to put out pollen tubes. These tubes grow through the stigma and enter the style; grow down the style and enter the cavity of the ovary; reach the ovules and enter their micropyles; and finally penetrate the ovule to the egg. Throughout this progress of the tube the male cells are in its tip, and when the egg is reached they are discharged from the tube and one of them fuses with the egg. This is the act of fertilization, and through it the egg becomes an oöspore.

An important difference between Gymnosperms and Angiosperms should be noted here. In Gymnosperms the pollen reaches the ovules, for they are exposed, but in Angiosperms the pollen reaches only the surface (stigma) of the pistil that encloses the ovules.

The oöspore, lying in the midst of the ovule, at once begins to germinate, and forms a young plant, or embryo. When the embryo is forming, the ovule develops a hard coat outside, and a seed is the result.

The seed coats are varied in many ways, as in the pea and the Brazil nut, but their internal anatomy follows the same general pattern, and they nearly all contain food for the embryonic plant. It is this food in grains and in nuts which is used as foodstuff by man. The three kinds of food stored in seeds are starch, oil and albuminous substances called proteids. The young seedling does not push its way straight out of the ground, but sends up an arched part of the stem, known as the hypocotyl, and when the surface of the ground is broken the stem straightens and the cotyledons appear.

The lower elongating tip of the hypocotyl directs its growth downward—that is, toward the earth—even if it has to curve about the seed to do so. It is exceedingly sensitive to surounding influences,

a condition that is called irritability, especially so to gravity, a condition that is called geotropism, the root being said to be geotropic. If the same stimulus and response that directs the root-tip toward the soil continues to direct it within the soil it continues to grow directly downward and becomes a tap-root. When such a root, having entered the soil, begins to send out branches, these do not respond to the stimulus of gravity as does the tap-root, for they extend through the soil in every direction. It is likewise sensitive to light, the stem being attracted and the root repelled. With the establishment of roots in the soil, and the exposure of green leaves to the light and air, germination is over, for the plant is able to make its own food.

CHAPTER IV

CLASSIFICATION OF PLANTS

The first great division of the plant kingdom comprises the Algæ and Fungi, grouped under the term "Thallophytes," meaning plants wherein such special vegetative organs as leaves and roots are either lacking or rudimentary.

The Algæ grow in the water, and hence their habits are adapted to a water environment. They are often called sea-weeds, but altho they are very abundant along sea-coasts they are also found in fresh waters. Some of them are so small that the individual bodies are visible only under the microscope, but others are large, the sea-kelp having been known to have a stem nine hundred feet long.

Altho all algæ contain chlorophyll, and hence are able to make their own food, they do not all appear green, for in many of them the chlorophyll is obscured by other coloring matters. The four great groups of Algæ are named from the general color of their bodies.

The Blue-Green Algæ, or the "Green Slimes," form blue-green or olive-green patches on damp tree trunks, rocks and walls. The name of the group refers to the fact that in addition to the chlorophyll the cells contain a characteristic blue coloring matter which does not mask the green, but combined with it gives a bluish-green tint to the plants when seen in masses. Not all the blue-green Algæ are bluish-green in tint, however, for the presence of other substances may disguise it, and the color may be yellow, or brown, or even reddish. The color of the Red Sea, which has given it its name, is due to the presence under certain conditions of immense quantities of one of the blue-green forms.

The green algæ are so named because the green of the chloroplasts is neither modified nor obscured by other colors, and the plants have a characteristic grass-green color. Some of the green algæ are associated with the blue-green algæ in the pollution of water reservoirs.

The brown algæ, of which the giant kelp of the Pacific coast, with a length of 900 feet, is the largest, are all anchored plants, chiefly marine. The first great group of brown algæ, of which a small form, Ectocarpus, is a well-known representative, is distinguished by its swimming spores and its similar gametes. The smaller group, besides the common "rock-weed" or Fucus, contains the famous gulf-weed, or

Sargasso weed, which makes a floating bank of dense weed in the North Atlantic, known as the Sargasso Sea. These differ from the first group in producing no swimming spores, and in its dissimilar gametes (eggs and sperms).

The red algæ are mostly marine forms, and receive their name from the fact that a red coloring matter completely masks the chlorophyll. As a consequence the plants are various shades of red, violet, dark purple, and reddish brown, often beautifully tinted. In general, the bodies are much more graceful and delicate than those of the brown algæ. There is the greatest variety of forms, branching filaments, ribbons, and filmy plates, prevailing; and often profuse branching occurs, the plants resembling mosses of delicate texture.

The reproduction of the red algæ is very peculiar, being entirely unlike that of the other algæ. No swimming-spores are produced, but sporangia occur that produce and discharge spores without the ability to swim. Since each sporangium usually produces four such spores, they are called tetraspores. Floating about in the water, instead of actively swimming, they finally germinate and produce new plants. The sexual reproduction, however, is most remarkable. The sperms, like the tetraspores, are without cilia, and simply float into contact with the carpogonium, whose form is like that of a flask with a long, narrow neck. In the bulbous base of the carpogonium the female cell is developed. In a very simple case the floating sperm comes in contact with the long neck, the two walls become perforated at the point of contact, the contents of the sperm enters and passes to the carpogenic cell, and thus fertilization is accomplished. As a result of fertilization there appears on the plant a spore-containing structure like a little fruit. The spores it contains produce the alga plants again.

The Fungi do not contain chlorophyll, and this fact forms the sharpest contrast between them and the algæ. The presence of chlorophyll enables the algæ to be independent of any other organism, since they can manufacture food out of carbon dioxide and water. The absence of chlorophyll compels the Fungi to be dependent upon other organisms for their food. This food is obtained in two general ways: either (1) directly from living plants and animals, or (2) from organic waste products or dead bodies. In case a living body is attacked the attacking fungus is called a "parasite," and the plant or animal attacked the host. In case the food is obtained in the other way the fungus is called a "saprophyte." For example, the rust that attacks wheat is a parasite, and the wheat is the host; while the mold which often develops on stale bread is a saprophyte.

Bacteria include the smallest known living forms of fungi, some of which are spherical cells only 1/25,000 inch in diameter. It is estimated that 1,500 of certain rod-shaped forms, placed end to end,

would about stretch across the head of an ordinary pin. Even to distinguish ordinary bacteria, therefore, the highest powers of the microscope are necessary. However, they are so very important to man, on account of their useful and destructive operations, that every student should have some information about them. Public attention has been drawn to them chiefly on account of the part they play in many infectious diseases.

Bacteria are found almost everywhere—in the air, in the water, in the soil, in most foods, and in the bodies of plants and animals, as regular inhabitants. Many of them are entirely harmless, some are useful, and others are very dangerous. The "pure" water of springs and wells contains abundant bacteria, while in stagnant water and sewer water they swarm in immense numbers.

Reproduction is by cell division, as among the blue-green algæ, a group which the bacteria resemble in many ways. This cell division is remarkably rapid in bacteria, resulting in such prodigious multiplication of individuals in a comparatively short time that it is impossible to imagine what would happen if bacteria were left free to reproduce to their full capacity. Bacteria have been observed to reproduce themselves in fifteen to forty minutes after their formation; that is, a single generation of such bacteria is that length of time. It would be interesting to determine the number of progeny from a single bacterium at the end of twenty-four hours if such a rate were maintained.

Yeasts are much larger than bacteria and have a more complex cell structure, for there is present a clearly defined nucleus. The cells reproduce in a peculiar method called "budding." This consists in a cell putting out one or more projections which gradually enlarge and finally become pinched off. Often the cells thus produced cling together in short, irregular chains. The chief interest in connection with yeasts is the important part they play in the fermentation of sugar solutions, "splitting" the sugar into alcohol and carbon dioxide, a process also induced by certain bacteria, but chiefly by the yeasts.

Fermentation by yeasts is employed on a large scale in the manufacture of beer, wine, and spirits, and in the making of bread. In the last-named process the dough is inoculated with yeast plants and placed in a sufficiently warm temperature to induce rapid growth. The plants begin to reproduce actively by budding, the sugar in the dough is split into alcohol and carbon dioxide, and the latter, a gas, expands and puffs up the dough, making it light and porous; that is, causing it to "rise."

One of the most common of the Mucors, or "bread molds," forms white, furry growths on damp bread, preserved fruits, manure heaps, etc. It may be grown easily by keeping a piece of moist bread in a

warm room under a glass vessel. The sources of its food supply indicate that it is a saprophyte.

Rusts are destructive parasites that attack almost all seed plants, but those that attack the cereals are of special importance. Wheat, oats, rye and barley all have their rusts, and in the United States there is a yearly loss of several million dollars on account of the ravages of the wheat rust alone, scarcely a field being entirely free from the pest. Naturally, these parasites have been investigated persistently, but while very much has been learned about their life histories and behavior no remedy has been discovered. It has been found that certain varieties of wheat resist the rust better than others and that varieties ripening early escape serious injury; and these facts may lead to the breeding of resistant and early races.

The popular idea of a fungus is that of a fleshy, colorless form, such as the mushroom. This name is very indefinite, being sometimes applied to any of the fleshy fungi of the umbrella form, and sometimes including among such forms only those that are edible, the poisonous forms being spoken of as toadstools.

The life history of the ordinary edible mushroom of the markets will serve as an illustration. The mycelium of white, branching threads spreads extensively through the substratum of decaying organic material, and by those who grow mushrooms is called spawn. This mycelium, altho the least conspicuous part of the mushroom, is, of course, the real vegetable body. Upon this underground mycelium little knoblike protuberances rise (buttons), growing larger and larger until they develop into the umbrella-like structures commonly spoken of as mushrooms. This umbrella-like structure, however, corresponds to the sporophores that arise from the mycelia of other groups of fungi, except that it includes a large number of sporophores organized into a single large body. Therefore, the real mushroom body is a subterranean mycelium, upon which the structures commonly called mushrooms are the spore-bearing branches. In pulling up a mushroom, fragments of the mycelium may often be seen attached to it, looking like small rootlets.

The puffballs are fleshy fungi that differ from the mushrooms in having the spores enclosed until they are ripe. There is a subterranean mycelium, as in the mushrooms, but the spore-bearing structure is a fleshy, globular body containing irregular chambers lined with the spore-producing layer. When young this body is solid and white, but as the spores mature it becomes yellowish and brownish, gradually dries up, and finally is only a brown, parchment-like shell containing innumerable exceedingly small spores that are discharged by the breaking of the shell. Some of the puffballs become very large, reaching a diameter of twelve to eighteen inches.

Lichens are abundant everywhere, forming splotches of various

colors on tree trunks, rocks, old boards, etc. They have a general greenish-gray color, but brighter colors also may be observed. The great interest connected with lichens is that they are not single plants, but that each lichen is formed of a fungus and an alga living together so intimately as to appear like a single plant. In other words, a lichen is not an individual, but a firm of two individuals very unlike one another. If a lichen be sectioned the relation between the two constituent plants may be seen. The fungus makes the bulk of the body with its interwoven mycelial threads, in the meshes of which lie the algæ, sometimes massed. It is these enmeshed algæ, showing through the transparent mycelium, that give the greenish tint to the lichen. It has been found that the lichen-alga can live quite independently of the lichen-fungus. On the other hand, it is has been found that the lichen-fungus is completely dependent upon the algæ, for the germinating spores of the fungus do not develop far unless the young mycelium can lay hold of suitable algæ. Artificial lichens also have been made by bringing together wild algæ and lichen-fungi. Lichens, therefore, are really combinations of a parasitic fungus and its host, the parasitism being peculiar in that the host is not injured. The fungus lives upon the food made by the alga, and the relation suggested is that the alga is enslaved by the fungus.

With the Liverworts a new division of the Plant Kingdom is entered, known as the Bryophytes, possessing "archegonia," but no vascular system. Among these the simplest of the archegonia forms are found.

Mosses are very abundant and familiar plants. They grow in all conditions of moisture; many of them can endure drying out wonderfully, and hence they can grow in very much exposed situations, as do many lichens. In fact, lichens and mosses, being able to grow in the most exposed situations, are the first plants to appear upon bare rocks and ground, and are the last plants seen in climbing high mountains or in going into very high latitudes.

Mosses have great power of vegetative multiplication, new leafy branches putting out from old ones indefinitely, thus forming thick carpets and masses. Bog mosses often completely fill up bogs or small ponds and lakes with a dense growth, which dies below and continues to grow above, so long as the conditions are favorable. These quaking bogs, or "mosses," as they are sometimes called, furnish very treacherous footing unless rendered firm by other plants.

The conspicuous part of an ordinary moss plant consists of a more or less erect and usually branching stem bearing numerous delicate leaves. The plant is evidently able to make its own food, and it is anchored to its substratum by hairlike rhizoids. Its power of vegetative propagation has been described. At certain times there appears at the end of the main stem, or at the end of a branch, a rosette of

leaves, often called the moss flower. In the center of this rosette there is a group of antheridia and archegonia, sometimes both kinds of organs in a single rosette, sometimes only one kind. From the fertilized egg cell of the archegonium arises the capsule containing spores (sporophyte), from which the new moss plant springs.

The third division, or Pteridophytes, is represented first by the ferns, but also includes the "horsetails" and club mosses. The ferns are well-known plants and the ordinary forms are easily recognized; in fact, the general appearance of the large compound leaves is so characteristic that when a leaf is said to be fernlike a particular appearance is suggested. In the tropics not only are great masses of the low forms to be seen, from those with delicate and filmy, mosslike leaves to those with huge leaves, but also tree forms with cylindrical trunks encased by the rough remnants of fallen leaves, and sometimes rising to a height of thirty-five to forty-five feet, with a crown of great leaves fifteen to twenty feet long.

If an ordinary fern be examined it will be discovered that it has a horizontal underground stem or rootstock, which sends out roots into the soil and one or more large leaves into the air. These leaves, appearing to come directly from the soil, were once supposed to be different from ordinary leaves, and were called fronds; but altho the name is still used in connection with fern leaves it is neither necessary nor accurate. These leaves are usually compound, branching either pinnately or palmately. There are two peculiarities about fern leaves that should be noted. One is that in expanding the leaves seem to unroll from the base, as tho they had been rolled from the apex downward, the apex being in the center of the roll. When unrolling this gives the leaves a crozier-like tip. The other peculiarity is that the veins fork repeatedly. This combination of unrolling leaves and forking veins is very characteristic of ferns.

"Probably the most important fact about the fern body," says Coulter, "is that it contains a vascular system. The appearance of this system marks some such epoch in the evolution of the plants as is marked among animals by the appearance of the backbone. As animals are often grouped as vertebrates and invertebrates, so plants are often grouped as vascular plants and non-vascular plants, the latter being the Thallophytes and the Bryophytes, the former the ferns and the seed plants. The presence of this vascular system means a special conducting system, and in connection with it there are developed the first roots and the first complex leaves.

"On account of the vascular system, and other resistant structures, the remains of ferns have been preserved in great abundance in the rocks. These records show that the ferns are a very ancient group, occurring in special abundance during the Coal-measures.

"Another striking fact about this leafy body of the ferns is that it

never produces sex organs, but does produce spores abundantly. This means that it is the sporophyte in the life history of the fern, and when it is contrasted with the sporophyte of Bryophytes the differences are remarkable. Among the liverworts and the mosses the sporophyte is a leafless structure attached to the gametophyte, and dependent on it, while the gametophyte is a leafy body doing chlorophyll work. Among the ferns, however, the sporophyte is an elaborate leafy structure and entirely independent. Therefore, when one ordinarily speaks of a moss and a fern, the gametophyte is referred to in the former case and the sporophyte in the latter. This means that in passing from mosses to ferns plants have transferred the chief work of food manufacture from the gametophyte to the sporophyte, which has thus become the conspicuous generation.

"The sharp and easily marked distinction between the prothallus (gametophyte) and the fern plant itself (sporophyte) has led certain writers on 'biology' to consider the fern as a typical plant for the purpose of comparison with certain typical animals which are assumed to represent a similar stage of evolutionary development. Aside from the dangers which arise from such an assumption, it must be said that in many respects ferns are not typical. They should not be regarded as the ancestors of the present flowering plants, but as a somewhat highly specialized offshoot from the main line of descent which at the present geological age is not 'biologically successful' in competition with the seed-bearing forms."

The Gymnosperms are one of the two groups of seed plants, the most familiar ones in temperate regions being pines, spruces, hemlocks, cedars, etc., the group commonly called evergreens It is an ancient group, for its representatives were associated with the giant club mosses and horsetails in the forest vegetation of the Coal-measures. Only about four hundred species exist to-day as a remnant of its former display, although it still forms extensive forests. Gymnosperms are very diverse in habit. They are all woody forms, but they may be gigantic trees, trailing or straggling shrubs, or high-climbing vines. There are two prominent living groups of Gymnosperms.

Cycads are tropical forms with large fernlike leaves. The stem is either a columnar shaft, crowned with a rosette of large compound leaves, with the general habit of tree-ferns and palms, or they are like great tubers, crowned in the same way The tuberous stems are often more or less buried. In ancient times cycads were very abundant, but now they are represented by about eighty species, scattered through the Oriental and Occidental tropics. They are especially interesting in their resemblance to ferns, and some of them might be mistaken for ferns did they not bear large seeds.

Conifers are the common Gymnosperms, often forming great for-

ests in temperate regions. Some of the forms are widely distributed, as the pines, while some are now very much restricted, as the gigantic redwoods, "Sequoia," of the Pacific slope. The habit of the body is quite characteristic, a central shaft extending to the very top. In many cases the branches spread horizontally, with diminishing length at the top, forming a conical outline, as in the firs. This habit gives the conifers an appearance very distinct from that of the other trees.

The large cone of the pine is made up of sporophylls that become very thick and hard, and that are packed closely together until they spread apart to let out the seeds. On the upper side of each sporophyll, near its base, there are two sporangia, in each one of which there is a single large spore (megaspore). The cone, therefore, is a group of carpels.

It is evident that the pine tree, bearing these sporangia, is the sporophyte in the life history; that is, it is the sexless generation. The sporophyte has now become so prominent that it seems to have become the whole plant. The pine being heterosporous, there are male and female gametophytes. The small spores (pollen grains) germinate and produce very small male gametophytes. Only a few cells are formed, and these remain in the pollen grain. The single large spore within the ovule is peculiar in never leaving it; it is never shed, but produces a female gametophyte which lies embedded in the center of the ovule. The reason, therefore, why the gametophytes of such plants are not ordinarily seen is that one is within the pollen grain and the other within the ovule.

"Before fertilization can take place," remarks Coulter, "the pollen grain, which develops the male gametophyte with its sperms, must be brought to the ovule, which contains the female gametophyte with its archegonia. The pollen grains (microspores) are formed in very great abundance, are dry and powdery, and are scattered far and wide by the wind. In the pines and their allies the pollen grains are winged, so they are well organized for wind distribution. So abundant is the pollen of conifers that the occasionally reported "showers of sulphur" are really showers of pollen from some forest of conifers. To aid in catching the fallen pollen the scale-like carpels of the cone spread apart, and the pollen grains, sliding down their sloping surfaces, collect in a little drift at the bottom of each carpel, where the ovules are found.

"In this position each of the most favorably placed pollen grains begins to put forth a tube (pollen tube). This tube, containing the two sperms in its tip, grows through the ovule and reaches the archegonia. Then the sperms are discharged, and when they reach the egg, fusion takes place and fertilization is accomplished"

The Angiosperms are the flowering plants. In many flowers there is no regularity in the number of members in each set. For example,

in the water lily petals and stamens occur in indefinite numbers, and in the buttercup the same is true of stamens and carpels In most flowers, however, definite numbers appear either in some of the sets or in all of them. When these definite numbers are present they are prevailingly either three or five; that is, there are either three or five sepals, petals, stamens and carpels; altho it is very common to have two sets of stamens, in which case they number six or ten. These numbers appear so constantly in great groups that the two grand divisions of Angiosperms, called Monocotyledons and Dicotyledons, are characterized by them, the former having the parts of the flower in threes, the latter in fives. Not a few Dicotyledons have flowers with the parts in threes, and a still larger number have them in fours.

In many cases stamens and pistils are not found together in the same flower. In such cases there are staminate flowers—that is, those without pistils; and pistillate flowers—that is, those without stamens. These two kinds of flowers may be borne upon the same plant, which is then said to be monœcious (one household); or upon different plants, which are then said to be diœcious (two households). These terms are applied indifferently to the plants or to the flowers, either the plant or the flowers being spoken of as monœcious or diœcious. About forty monocotyledonous familes are recognized, containing numerous genera and about twenty thousand species.

The Dicotyledons are a much larger group than the Monocotyledons, containing more than 200 families and about 100,000 species. Most of them are easily recognized by the floral number five or four, the net-veined leaves, and the arrangement of the vascular bundles of the stem in a hollow cylinder.

In the lower stretches of the Dicotyledons there are a number of small families that include the most common hardwood or deciduous trees, and this assemblage of conspicuous forms may be considered together without selecting any special family. They include elm, sycamore, walnuts, hickories, oaks, chestnuts, willows, poplars, cottonwoods, birches, beech, etc. These trees are all characterized by their simple and inconspicuous flowers, which are usually wind-pollinated.

Passing from these forms, which in the older terminology, are not inaptly described as "apetalous," there is the very large group of plants which have distinct and separate petals which are well described by the adjective polypetalous. As a type one might perhaps take the flower of the flax, the parts of which are regular and symmetrical, and show, except in the ovary, no fusion.

It is not unreasonable to suppose, however, in a general way, that the irregular flowers, like the sweet pea, for example, have been the result of later development than the simpler and symmetrical forms. One potent factor in the development of partial fusions and of flowers which are not radially symmetrical is probably that of the

relation of the flower to insect visitation for the furthering of cross-pollination. A tendency is found in general toward modifications which, as they can be interpreted, make for the restrictions of the movements of insects or parts of insects among the floral organs and thus render more probable the carrying of pollen from one flower to another.

The culmination of this tendency, along with the condition known as epigyny (the insertion of the calyx, corolla and stamens on the ovary), is seen in the sympetalous dicotyledonous type. In the sympetalous or gamopetalous flower the petals are fused into a bell or tube, a condition which may or may not be accompanied by other fusions. It is conceded that the Compositæ (Sunflowers, Daisies, Asters), which are of this sympetalous type, represent the final and highest development of the dicotyledonous flower. Composites are found everywhere, but are most numerous in temperate regions, where they are usually herbs. The name of the family suggests the most conspicuous feature, namely, the organization of the numerous small flowers into a compact head which resembles a single flower, formerly called a compound flower.

CHAPTER V

HOW TO KNOW THE FLOWERS

BOTANY, scientifically considered, is a subject which necessarily can have a comparatively limited appeal as contrasted with that larger element of interest which has come to be known as Nature Study. There are few who will wander far afield with magnifying glass and herbarium; there are many who will more greatly enjoy a stroll through the woods or over the meadow adjacent to outlying suburbs if they know the flowers they encounter.

The world of flowering plants is divided into two great divisions: the monocotyledons and the dicotyledons. Each of these two groups is divided into orders and every flower can be placed in one or other of these orders. The following are the orders of the monocotyledons, and the flowers typical of each order:

1. Marsh Plants *(Helobiæ)*. The most common flower belonging to this order is the Arrowhead, a water plant growing from a few inches to several feet high, with arrow-shaped leaves. The flowers are small, white, growing in whorls of three on a leafless stalk. The flower is unisexual, the stamens and pistils being found on different blossoms. Among other well known plants of this order are the water plantain and the common pond weed.

2. Sedges and Grasses *(Glumifloræ)*. This order includes all the common grasses, and its type plant is Timothy grass. The order also includes the cereals, such as wheat, oats and corn. Bulrushes belong to this family, and the bamboo from which furniture is made is but a larger grass. The flowers are small.

3. *Spadicifloræ*. The salient characteristics of this order is the manner in which the flowers grow on a fleshy spike. The type blossom is the Jack-in-the-Pulpit The spiral, hood-like spathe is not part of the flower at all, it is a protecting leaf. and the tiny flowers grow on the shielded spike. Very widely different plants belong to this order, of which the cat-tails are the best known in the United States. The cocoanut and date palms have the same flowers, the true arums of the tropical forests.

4. Spiderworts. *(Enantioblastæ)*. Here the typical flower of our fields is the spiderwort. The flower is a brilliant blue with three petals. The plant grows under hedges, and the little blue blossoms

gleam out from masses of its own leafage. They are very perishable, like their cousins the day flowers, so called because the blossoms only last a single morning.

5. *Lilliforæ.* The typical flowers of this order are the lilies, of which the Easter lily and the tiger lily are the most showy examples, being so familiar as not to need description. The wild tiger lily is the most conspicuous flower of the western prairies. The large blue flag, the spring crocus, the snowdrop, the daffodil and the narcissus are familiar blossoms of this most delicate order. Little though it might be expected, the pineapple belongs to this same group.

6 *Scitamineæ.* These are all tropical plants, of which the banana, the ginger plant and the arrowroot plant are the most commonly known varieties.

7. *Gynandræ.* This is the order which contains the orchids, comprising over ten thousand species of the most bizarre and decorative character. The snowy orchis is one of the commonest flowers that dots with its unusual beauty, the woods in May. Many of these blooms bear more than a slight resemblance to gorgeously colored butterflies and insects. They possess a peculiar fascination because of their complicated arrangements for pollination by insects.

The orders of the dicotyledons are far more numerous, including a large number of the trees:

1. *Piperinæ.* This order contains only the peppers and the cubebs.
2. *Juglandifloræ.* Walnut, hickory, bayberry, etc.
3. *Salicifloræ.* Willow, poplar and aspen wood.
4. *Quercifloræ.* Oak, beech, chestnut and birch.
5. *Urticinæ.* Hops and the stinging nettle may be considered as the typical flowers of this order. The elm is the most prominent tree with this flowering system.
6. *Centrospermæ.* The field chickweed, whose blossom is like a tiny carnation, shows its profuse starry white flowers in dry and rocky places, blossoming from May until July. The common chickweed, which has smaller flowers, is found in damp places everywhere and is much used as food for song birds. The chickweed form found in grassy places is known as the stitchwort. In this order are the carnations and the pinks, which lend themselves so marvellously to development in the hands of floriculturists. Rhubarb, spinach and sorrel are the principal members of this family, which find their way to the table, and in the West, pig-weed is used as a salad.
7. *Polycarpicæ.* This is a very large order, containing plants of widely different characteristics. To these the water-lilies belong, these snowy cups of delight whose recesses glow with a golden radiance unsurpassed by any other bloom. The whole wealth of color that lies in buttercup and crowfoot blossoms follows the same plan of flowering as the water lilies, so do also the hepatica and wood anem-

ones which give the first touch of color to the woods of early spring. The golden marigold and the blood-red peony, as well as the trailing purple clematis, belong here.

8. *Rhoedinæ.* The poppies, famous for their sleep-producing qualities, are the typical flowers of this order. When the blossom is in full bloom it shows four petals and no calyx. It is the seed pod of the oriental poppy which contains opium. Among the commonest of the field flowers of this group is the shepherd's purse, with a very small white flower, poppy-like in form, the seed pod of which resembles a purse. The most persistent and damaging of all weeds—save for the thistles—is the wild mustard, whose brilliant canary yellow flowers are the admiration of the passer-by and the despair of the farmer. A number of our vegetables, such as cauliflower, cabbage, turnip and horseradish, belong here, and like most plants of this order, these have attractive flowers.

9. *Insectivoræ.* This class of plants feeds upon insects. There are four very famous examples, the Venus fly-trap, the sun-dew, the pitcher plant and the side-saddle flower. Of these the sun-dew is fairly common in the marshes of the Carolinas. When the sun shines upon its leaves, they look as if studded with dewdrops, hence its name. But these drops are sticky and if an unwary insect happens to alight upon them, it is held fast and the spiny leaves close upon it, while the plant sucks out its juices, throwing the carcass away when its carnivorous meal is done. In the pitcher plant the insects are attracted by a sweet liquid at the base of the pitcher-leaf, and the down pointing hairs prevent the victim from returning to the light of the open day. The flowers of the sun-dew are white, growing in a one-sided raceme which bends in such a way that the fresh blossom is always uppermost.

10. *Saxifraginæ.* The most common flower of this order is the swamp saxifrage, with small greenish or reddish-white five-petalled flowers in a large cluster. Often its leaf stalks are noticeably tinged with red. The luscious gooseberry and the tart currant are better known for their fruit than their flowers, although these indeed are pleasing to behold. The syringa, which possesses one of the most overpowering sweet scents in the plant kingdom, has waxen white flowers which suggest by their beauty the exotic odor they convey. The sycamore is the principal tree belonging to this order.

11. *Rosifloræ.* The typical flower of this order is the rose in all its bewitching array of varieties, although in its wild state it is a simple, white-pink blossom with single petals. It is easy to see how the hawthorn, June-berry and raspberry should have similar flowers, but one does not immediately think of the strawberry as similar, though its blossom is alike. The fragrant beauty of apple blossoms and pear blooms add to the fame with which this flower group is

justly held, and even the sour crab apple and the quince find a measure of sweetness for their blossoms.

12. *Leguminosæ.* Leguminous plants perhaps may be awarded the prize as the most useful to the agriculturist, since they alone have the capacity of attracting to their roots the bacteria which gather nitrogen from the air held in the interstices of the soil. All the peas and beans belong to this family, and the sweet pea can be taken as a typical flower, seeming, as it does, like some fairy butterfly about to take flight. The upper petal, which looks as though it were double, is but a single one. There are two small ones on either side and the bag-shaped portion of the flower, which is known as the keel, is composed of two petals, making five in all. Its fertilization is of unusual interest, the pistil being situated immediately beneath the stamen inside the keel in such a way that when a bee alights upon the keel, the pollen is thrown from the stamens to the pistil, and the plant is fertilized, the keel thereafter remaining open. The loveliest of all the flowers belonging to this order is the wistaria, whose only rival is the graceful laburnum tree. Extraordinary though it seems, the familiar red clover is similar in structure to the sweet pea, save that the corolla is lengthened into a tube. Each of the score of little tubular flowers upon the one clover head is complete with a keel structure as in the sweet pea.

13. *Gruminalæ.* The typical flower of this order is the common geranium, as recognizable by its strongly veined leaves as by its home-like vivid red blooms. Its flowers are unusually conspicuous and the seeds of the wild geranium are so devised that when ripe they spring away from the parent plant as though shot from a Lilliputian rifle. The common orange nasturtium and blue flax, though so different in color and shape of their blossoms, are similar in form to the geranium.

14. *Tricoccea.* The crown of thorns may be selected as the type flower of this order, but the spurge is the most common member of the family in the eastern states. The five-lobed cup-shaped involucre appears like the flower itself, but in truth it is composed of a single female flower in the middle of the involucre surrounded by numerous male flowers, consisting of a single stamen. The cypress is the largest tree belonging to this order.

15. *Sapindinæ.* Under this order the most attractive feature in our fields and woods is the stag-horn sumach, which every autumn illuminates the hillsides with the masses of its flame-like sprays. Many people who are afraid to use these decorations need have no fear, as the poison sumach, although closely related, has whitish or dun-colored fruits. In both types the flowers are greenish or yellowish white, in clusters. There are several large trees belonging to this order, among them the sugar maple, the horse chestnut and the holly.

16. *Frangulinæ.* The only plants of this order which are found in the United States are creepers, of which the grape vine is familiar. The Virginia creeper, sometimes called the American ivy, is the most beautiful. Its small clustered, greenish-white flowers which appear in July are followed by blood-like sprays in Autumn, on which the small, blackish berry appears. The flowers are anti-petallous, stamens and pistils rising right from the green calyx.

17. *Columniferæ.* This order at once brings to one's remembrance that toothsome candy, the marshmallow, which is made from the root of the plant of that name. The most prominent flowering species in America is the rosemallow, which grows higher than one's head and opens her five large, rose-colored petals in the late summer. The holly-hock, beloved of all domestic gardeners, is a mallow, and derives its name from the word "holy" because it is a native of Palestine. There are some large trees belonging to this family, among them bass wood, the linden and the flowering maple.

18. *Sistifloræ.* The typical flowers of this order have long been acclaimed by lovers of beauty among the prettiest of the entire plant kingdom. Here are found all the violets and the pansies. The common violet not only is famed in song and story, but it also has the added advantage of blooming early in the spring and being a herald of the dawning of the year. It is a matter of interest to note that the tea shrub belongs to this group and the camelia is one of the most ornamental of the shrubs with a similar flowering system. The flowers of the camelia are showy and heavily scented.

19. *Passifloræ.* To this order belong two very familiar types, the one famed throughout the world for the beauty and complexity of its flower, the other for the variegation and coloration of its leaves. The passion flower is not only the type but also the loveliest of this group. Its petals are ten in number (and by some are deemed reminiscent of the twelve apostles with the exception of Peter and Judas Iscariot), and the styles of the pistil are nail-like (reminding of the nails used in the crucifixion), and the corona resembles a crown (the crown of thorns). There are some sixteen other symbols of the Passion found in this flower. Many species of begonia are cultivated because of the ornamental nature of their leaves. The Himalaya begonia, in addition, has a marvellous blossom, in which the parts of the passion flower appear in very different form and, curiously enough, it is esteemed by Buddhist devotees.

20. *Opuntinæ.* To this order belong all the cacti, fleshy and succulent denizens of the desert. Despite their leafless condition and the arid lands in which they flourish, many of them have flowers of surpassing beauty, rising directly from the stem. Even the common prickly pear has yellow blossoms of great fragility and charm, and the night blooming cereus needs not to take second place in beauty to

any other flower in the world. The century plant, which blooms but once, also has a flower of weird attractiveness.

21. *Thymelaeinæ.* Nearly all the members of this order are small shrubs and trees with small leaves. The single important American species is the lady-laurel, valuable as fiber. The famous lace bark comes from one of the Daphne trees. This is not to be confused with mountain laurel.

22. *Myrtifloræ.* The evening primrose is the most widely disseminated flower of this group. It grows on an average of from three to four feet high, with pale yellow flowers of four heart-shaped petals that open only in the evening and last but for one single night. The fuchsia has an outward appearance differing greatly from that of the evening primrose. Its long red calyx seems to make a double flower, yet if the blossom be lifted so that its drooping appearance is overcome and the long calyx forgotten, its formation will immediately appear similar to that of the evening primrose. One of America's very large trees, the eucalyptus or blue gum of Australia, which has been acclimatized in California and has spread so rapidly, is one of the myrtles, all of which belong to this order. The pomegranate, which for centuries untold has been considered one of the most luscious fruits, has a large red flower, as showy as the fruit.

23. *Umbellifloræ.* The most familiar of the parsleys belonging in this group is the wild carrot, which so profusely decks the highways throughout the summer with its white, lace-like clusters, while among the common yellow flowers the early meadow parsnip brightens the borders of streams in May and June with gold. The characteristic of this order is that the flowers grow like an umbrella. This may easily be seen in the wild carrot.

24. *Hysterophytæ.* Nearly all these plants are parasites, and the most familiar of them is the mistletoe, whose pale green leaves and transparent white berries bring tender reminiscences of Christmas time. Undoubtedly the most famous flower of this order—although it is seen in America only in botanical gardens—is the *Rafflesia Arnoldii,* which has a blossom over a yard in diameter and weighing fifteen pounds.

25. *Ericnæ.* Throughout the northern states and indeed on the hillsides over the greater portion of America the masses of blossom of the mountain laurel must be considered one of the greatest contributions to flower beauty that the United States possesses. Together with the trailing arbutus, its five-lobed flowers add grace and charm to many a dense thicket. The American rhododendron is one of the glories of the eastern mountains during the early part of July, but it is found only in places difficult of access. In the Tennessee mountains the bushes form veritable jungles, termed "hells" by the mountaineers, and the nectar is poisonous to a large proportion of

people. The May swamps and moist woods are made rosy by masses of the pink azalea, its funnel-shaped corolla with five long recurved lobes being familiar throughout the country. The huckleberry and the cranberry have blossoms of a similar character.

26. *Diospyrinæ.* The common persimmon is the only important American member of this order, which, indeed, has only commercial importance through its near cousin, the ebony.

27. *Primulinæ.* The "primrose by the river's brim," which is immortalized in verse, will always be considered as the most famous flower of this order. One of the widely spread blossoms of this type is the pimpernel, known as the "poor man's weather glass," for it folds its petals at the approach of rain, and never opens them at all upon a wet day. Its flowers are bright red, although occasionally blue or white, growing singly from the axils of the leaves. The loose-strifes, particularly the yellow variety, are found beside small brooks and in damp fields. The money-wort or creeping Jenny, with its brilliant yellow flowers, has become naturalized in the United States.

28. *Contortæ.* The commonest representative of this striking and beautiful order is the common milk-weed, so named from the milky juice in its stem. The dull pink clustered flowers, which appear in July, and later the puffy pods filled with silky tufted seeds, are familiar to nearly everyone who has spent part of the summer in the country. The young sprouts make an excellent pot herb, the silky hairs are used for stuffing pillows and mattresses and have been mixed with wool and woven to advantage, while there is a considerable manufacture of paper from the stout stalks. Equally familiar is the spreading dog-bane, bearing its flowers of rose color veined with deep pink. The lilac belongs to this order and the most prominent tree is the white ash.

29. *Tubifloræ.* A very large proportion of garden flowers belong to this order, such as the phlox, Sweet William, heliotrope and verbena. There are wild varieties of these, such as the wild phlox of New England, the wild Sweet William of the South and the beautiful little moss pink, which may be seen covering the rocks in almost every exposed locality.

30. *Personatæ.* Flowers dear to the hearts of all children find their place in this order, and there are none more familiar than the snap-dragon and the still more beloved butter-and-eggs. The snap-dragon flower is of two shades of yellow, and is two-lipped, closed in the throat. The petunia is the best known of the cultivated followers of this order, while the Irish potato and the tomato bring to remembrance their malefic cousin the deadly nightshade, from which the flowers of the common vegetables only differ slightly.

31. *Rubinæ.* With the word bluets or "Quaker ladies," arises to

the mind the thick carpet spread on fields and lawns by the dainty little blue flowers with their four-lobed corollas, which seem to be made of enamel. The common bush honeysuckle belongs to this order and the coffee plant is the best known shrub whose flowers are similar in character.

32. *Campanulinæ.* It is a far cry from the harebell to the pumpkin, yet the flowers of these two plants are allied. The American harebell is very close in character to the "bluebells of Scotland," and blooms from June to September on cliff and mountain side. Summer squash and cucumber show in larger form the flower system of the harebell, although they do not droop upon the stalk.

33. *Aggregatæ.* Aside from the teasel, nearly all the well-known flowers of this order have true composite leaves. There are several thousand of these, although perhaps the most familiar are the daisies and sunflowers, the dandelions and bachelor's buttons, and the corn flowers. The golden-rods and asters, both of them selected as state flowers in many states, belong to this order. When the question of a national flower for the United States was discussed, the golden-rod received preference, although it was never officially designated as such. Perhaps the fact that it receives the greatest share of blame in spreading "hay fever" may have contributed to this result, but it remains none the less the most widely distributed of the showy field flowers of the United States.

Thus far the flowering plants have been shown, all the foregoing belonging to the great class of angiosperms. There are yet four different orders which belong to the gymnosperm group. These all have naked seeds, as contrasted with the habit of the angiosperms in confining their seeds in an envelope. Furthermore, the flowers of the gymnosperms are all unisexual and in some cases, the male and female flowers are borne on separate trees. There are four orders:

1. *Cycads.* These trees formed one-third of all the vegetation of the Middle Ages of the Earth, and their palm-like foliage or fern-like forms dominated the whole of the Jurassic landscape. To-day there are few species, mainly woody, leathery-leaved plants confined to tropical and sub-tropical latitudes. They link the lower flowerless plants to the flowering.

2. *Ginkgoes.* Another of the forms still remaining on the earth to-day which was contemporaneous with the giant reptiles, the "antediluvian monsters" of tens of millions of years ago, is the Maidenhair Tree of Japan, the ginkgo. Through extinct in wild state, it long has been regarded as a tree of marked symbolical fitness for temple gardens, and thus has been perpetuated. It is now widely seen in parks and botanical gardens.

3. *Conifers.* All conifers are trees or shrubs with woody stems, and the common character of plants of this order is the needle-shaped,

or flat needle-shaped character of their leaves. The Yew family forms one group, the Pine the other. Junipers, Cedar, Cypress, Tamarack, Larch, Fir, Hemlock, Spruce, Sequioa and Pine all belong to this family.

4. *Gnetinæ.* As the flowers in this small order possess a perianth, they anticipate the angiosperms. There are only three genera. One is the *Ephedra,* a leafless shrub of American and Asian deserts; the second is the *Welwitschia mirabilis,* which, after the cotyledons, bears only two leaves, which are a yard in length; the third is the famous genus of lianas or the climbing plants of the South American forests, with pairs of broad leaves, these giving the dense growth of tropical South America an appearance different from that which may be seen in any part of the world, and, in places, making travel impossible. These huge interlacing creepers (many of them a foot in diameter) form a monster twined-thicket effect that extends for hundreds of miles.

Lower down in the scale of vegetation come the Ferns and Club-mosses. Here may be distinguished eight orders:

1. *Ophioglossaceæ.* This order contains the common Adder's Tongue fern, and the equally well-known Moonwort.

2. *Marattiaceæ.* These are mainly tropical ferns, the remains of the somber tree-ferns of those somber forests of the Carboniferous period, which makes our coal-beds.

3. *Filices.* The ferns proper are a modern type, and show fewer resemblances to the old form. The Tree-Fern of Ceylon is the largest example of this family, to which the Common, Christmas, Royal Ostrich and Hart's-tongue ferns belong, as well as all the brackens.

4. *Water Ferns.* These are marsh-growing plants of which the Free-floater and the Marsh Clover are the most abundant species. Their differentiations from the other ferns is marked.

5. *Horse-tails.* The dwarfed descendants of the great trees of the coal forest, are curiously characteristic. Their leaves are almost lost to sight, being in the stem, and the branches spring out together at regular intervals. In South America one species of the horse-tails, Sentinel Haulms, may reach a height of 25 feet, but in America only the small swamp common horse-tails remain to tell the tale of former greatness.

6. *Lycopodiaceæ.* The common club-moss, again, is a lingering remnant of those giants of the coal forest, which rose over a hundred feet into the air without a branch (their trunks are found whole to-day in our coal mines).

7. *Selaginellaceæ.* Still more marked is the contrast between the fluted pillar of the Sigillaria of the coal forest and the tiny Alpine Moss, the sole remaining member of the family.

8. *Quill-worts.* Yet older and unchanged are the short, tuberous

stems of the quill-worts crowned with a rosette of stiff awl-shaped leaves. They undoubtedly formed a large part of the swamp growth of that flowerless forest, wherein no bird flew, but huge insects flitted, with grasshoppers (archaic) 20 inches long and primitive may-flies with wings six inches long. The cockroaches, too, were ten inches in length. It is to be noted that none of these, nor the spiders or the scorpions, were of any service in pollination as are so many insects to-day, and, in keeping, in all the plant world there was not a single flower.

Still lower in the botanical scale come the mosses and the liverworts. It is well not to mistake the archegonial receptacles of mosses for flowers; mosses have no flowers. There are eight orders and hundreds of species, but their differences are for a specialist.

Even more simplified are the lichens. These are what is known as symbiotic organisms, being actually two plant forms, fungi and algae, fused as one. Thus the fungus derives its organic nourishment from the alga as a parasite; and the alga receives inorganic substances and water from the fungus. The leaf-like vegetable growths on wet wood, the gray powdering scale that is found on naked rock—these usually are lichens.

The fungi, still lower in the scale of life than the lichens, are so important to mankind that their thirteen orders may be described: 1. Grapevine mildew and green mold. 2. Orange-red cup fungus on wood (common on decaying trees in forests). 3. Fungus of ergot and fruit tree canker. 4. Truffles. 5. Witches' broom. 6. Beer yeast, and wine yeast. 7. The fungus that kills house-flies (often seen as a clouded spot on a window around a dead fly). 8. Smut fungi of wheat, oats, barley and corn. 9. Rust fungi of wheat, barley, oats and rye. 10. Judas ear. 11. Tremella on decaying trees. 12. Mushrooms and toad-stools; and 13. Stink-horn and earth star.

The Algae fungi make a different group, wherein may be found bread mold, cheese mold, cabbage blight, potato disease and several diseases of insects.

The Algae comprise most of the sea-weeds, from the microscopic plant that makes "red snow" to the giant kelp of the Pacific as much as a hundred feet long. They are usually divided into three classes: green algae, including sea lettuce, water net, shield weed, green felt, and the stone-worts; brown algae, the vast majority of brown seaweeds, such as the rock weed, gulf weed and bladder kelp; and the red algae, of which Irish moss, carragheen and agar-agar are the best known.

Simpler forms are largely microscopic, and the simplest of all are the bacteria, such as those which cause influenza, consumption, cholera, tetanus and many others. The rod-shaped cells of the bacillus of

tuberculosis is only one-five-hundredth of a millimeter in length. They are all one-celled and their number is legion.

There are three classes of these one-celled organisms of which the highest is the Flagellates. The Euglena is the most famous example example of this class. It contains chlorophyl, therfore can manufacture food as a plant does; it has a simple mouth and can ingest solid food like an animal. The Euglena and other forms are free-swimming. Next lowest come the Blue-Green Algae, or the Fission Algae, and form gelatinous green growths in damp places. They form colonies by a gelatinous swelling of the cell walls. Lastly come the five types of bacteria—the round cell or chains called cocci, such as the germ of pus; the rod-shaped or bacillus, such as the germ of tetanus; the slightly curved or vibrio, such as the germ of cholera; the strongly curved or spirillum, such as the germ of enteric fever; and the spiral or corkscrew shaped, called spirochetes, such as the germ of syphilis. Fortunately, almost as many are friendly to man as are hostile, or the human race would be wiped out in a day.

CHAPTER VI

ORGANOGENY AND ADAPTATION (ECOLOGY)

Reference has already been made to the service which Schleiden did in promulgating the idea of the cell as the morphological unit of plant structure. As will be seen, he was not, indeed, the first to observe them, tho he was the first to properly understand their significance. Since the cell is the ultimate unit to which morphological discussions must necessarily hark back, it is well to examine a little more closely just what these cells are.

"A thin cross-section from the stem or leaf of any plant shows, when magnified, a network of cells not unlike those of the honeycomb. This fact was first discovered in 1667 by Robert Hooke, an Englishman, who happened to take such a section to test the improvements he was making on the microscope. The first real study of cell structure was made by Malpighi, an Italian, in the year 1671. The section thus examined appears to be divided into small chambers or cavities, separated from each other by a common wall. The single cavity with its enclosing wall, like a room in a house, received the name of cell. The origin of these cells, or elements of plant structure, was at first supposed to be similar to that of air bubbles in a somewhat viscous liquid, but this supposition was soon found untenable, as in no young growing tissues was there found any indication of the liquid in which the bubbles were supposed to form.

"At a much later period it was discovered that the wall, or membrane, which gave the name to the cavity which it surrounds, was really the less important part and that the cell contents were the only necessary element. This is shown by the fact that the wall is a product of the contents and that at certain periods of the plant's life the cell may exist without it. Discoveries of this kind gave rise to an entirely different conception of the nature of the plant-cell. It is now known that this, in its simplest or least differentiated condition, consists of a small portion of the viscous liquid known as protoplasm, in which, under ordinary magnification, no structures are visible. It is in this general sense that Reinke defines a plant-cell as follows: "An individualized, not farther divisible structure, consisting of or containing protoplasm which either shows life processes or has shown them."

"In studying the anatomy of a plant-cell," says E. L. Gregory in "Elements of Plant Anatomy," "it will be necessary to consider one in its ordinary condition of development—that is, as an element of any plant, differentiated sufficiently to perform the ordinary functions of plant-cells. Such cells are usually considered as consisting of two parts, wall and contents, or as it is frequently stated, wall and protoplasm, the latter including a nucleus and one or more vacuoles. Before taking up the study of these parts separately, it may be well to examine the cell as a whole in reference to several features—namely, size, form, mechanical and physiological principles, and finally to discuss briefly certain theories concerning organized structures in general. By far the greater number of plant-cells are microscopic, but they vary greatly in size. The smallest occur among the organisms known as bacteria. Some of these are spherical in form and measure from seven-tenths to one micro-millimeter (.001 millimeter) in diameter.

"Cells vary as much in form as in size; those without a membrane incline to the spherical shape, since the protoplasm composing them is in a half-liquid state. Many swarm-spores are pear-shaped, but they generally assume a spherical form on coming to rest. The forms of some naked cells are subject to rapid change.

"In all the higher plants new cells are formed by the growth of walls across the cavities of the old cells. The new walls join the old at certain angles, and when the cells are young they are inclined to a hexagonal form. As growth continues the form is liable to change in various ways. If the cell should grow equally fast in all parts it would tend to retain its original form. This very rarely happens, and even when it does, the shape of such a cell is influenced in a greater or less degree by the manner of growth of those surrounding it, as the growing wall is flexible and its shape easily changed by pressure or traction from without.

"The individuality of the cell is shown by the fact that each has its own predetermined manner of development. All young cells of any plant are, at first, nearly similar in form and size, but later on each cell is seen to follow certain laws of growth which are, to a certain extent, independent of all external forces. From these laws, together with various mechanical causes, arises the great variety of form in the cells of ordinary plants. The peculiar forms common to certain unicellular plants illustrate even better than those of higher ones the inherent tendency of cells to grow in a certain manner.

"From the small size of the average cell two advantages result to the plant: First, strength and solidity; secondly, the greatest possible amount of surface for the transfer of cell contents. The first insures mechanical support; the second is connected with those changes in the

chemical nature of the cell contents by which the life processes of the plant as a whole are carried on."

Herbert Spencer included a consideration of plants in his scheme of the "Principles of Biology." However some of his deductions may be regarded at the present time, the fact remains that he summed up in at least a convenient form the ideas of morphological differentiation as influenced by the idea of Evolution. It is true that Spencer's knowledge of plants was much of it second-hand, but his treatment of the subject was a philosophical one and in the main sound.

The problems of Morphology fall into two distinct classes, answering respectively to the two leading aspects of evolution. "Evolution," says Spencer in his "Principles of Biology," "implies insensible modificatons and gradual transitions, which render definition difficult—which make it impossible to separate absolutely the phases of organization from one another. Thus, on inquiring what is the morphological unit, whether of plants or of animals, we find that the facts refuse to be included in any rigid formula. The doctrine that all organisms are built up of cells, or that the cells are the elements out of which every tissue is developed, is but approximately true. There are living forms of which cellular structure cannot be asserted; and in living forms that are for the most part cellular, there are nevertheless certain portions which are not produced by the metamorphosis of cells. Obviously, the earliest forms must have been minute, since, in the absence of any but diffused organic matter, no form but a minute one could find nutriment. Obviously, too, it must have been structureless, since as differentiations are productible only by the unlike actions of incident forces, there could have been no differentiations before such forces had had time to work. Hence distinctions of parts like those required to constitute a cell were necessarily absent at first. And we need not therefore be surprised to find, as we do find, specks of protoplasm manifesting life and yet showing no signs of organization.

"A further stage of evolution is reached when the imperfectly integrated molecules forming one of these minute aggregates become more coherent, at the same time as they pass into a state of heterogeneity, gradually increasing in its definiteness. That is to say, we may look for the assumption by them of some distinctions of parts, such as we find in cells and in which are called unicellular organisms. They cannot retain their primordial uniformity, and while in a few cases they may depart from it but slightly, they will, in the great majority of cases, acquire a decided multiformity; there will result the comparatively integrated and comparatively differentiated Protophyta and Protozoa. The production of minute aggregates of physiological units being the first step, and the passage of such minute aggregates into more consolidated and more complex forms being the second step, it must naturally happen that all higher organic types

subsequently arising by further integrations and differentiations will everywhere bear the impress of this earliest phase of evolution.

"From the law of heredity, considered as extending to the entire succession of living things during the earth's past history, it follows that since the formation of these small, simple organisms must have preceded the formation of larger and more complex organisms, the larger and more complex organisms must inherit their essential characters. We may anticipate that the multiplication and combination of these minute aggregates or cells will be conspicuous in the early developmental stages of plants and animals, and that throughout all subsequent stages cell production and cell differentiation will be dominant characteristics. The physiological units peculiar to each higher species will, speaking generally, pass through this form of aggregation on their way toward the final arrangement they are to assume, because those primordial physiological units from which they are remotely descended aggregated into this form."

Goebel more recently, naming Spencer along with Hofmeister and Sachs as one who has contributed in a special degree to the science of organography, has proceeded along somewhat similar lines, tho with a far wider knowledge of the actual facts. In discussing the question of the elaboration of the plant body, his introductory statements are illuminating.

"It is manifest," he says, "that the distinction of organs must have originally been based upon differences of outer form. The word 'blade' indicates that the original conception of a leaf was that of a flat organ which was distinguished by this character from the usually cylindric stem; under the designation root all subterranean organs were reckoned. It is, however, now generally known that there are leaves which have all the appearance of shoots, and the converse is also the case.

"External form is closely connected with function and with anatomical structure. In the vegetative organs the form may change, accompanied by a change in anatomical structure; 'metamorphosis' may take place, and a flower-leaf is the homologue of a foliage-leaf, notwithstanding that it has quite a different form.

"The history of development of the stem of the leaf is usually different. In the first place the duration of development is unlike; leaves have limited growth, shoots have unlimited growth. But there are many shoots which normally exhibit limited growth; for example, the short shoots, or spur-shoots, of many conifers and broad-leaved trees. These, however, may under certain conditions become shoots of unlimited growth and be transformed into long shoots.

"A striking illustration is furnished by species of the genus Utricularia, which are among the most remarkable plants in the world. In this genus the floating 'shoots' of the water-form, as well as the creep-

ing 'stolons' of the land-form, are homologous with leaves, but the difference between stem and leaf has entirely disappeared. The organs which are homologous with leaves produce flowers and other shoots and exhibit unlimited growth, and that they are really leaves with prolonged apical growth is only to be determined by a careful comparative study. Every distinction then that we may draw between shoot and leaf is only relative, is not fundamental.

"There is, however, this point still to notice: Leaves are in most cases outgrowths of shoot-axes and they arise on their vegetative point as lateral members; nevertheless terminal leaf-organs—organs arising from the end of a shoot-axis—are known. They occur in the flowers of many plants; the cotyledon in many monocotyledonous plants is terminal in the embryo. There are also monocotyledonous embryos upon which leaves arise, altho no vegetative point of the axis is visible, and a similar condition is also found in Isœtes. Further, the vegetative body of Lemna is nothing else than a leaf producing leaves; it is not a leafless twig, as is commonly assumed.

"A plant-body in which the shoot-axis does not exhibit differentiation into stem and leaf is termed a thallus. The expression thallus, which signifies nothing more than shoot, was first used by Acharius in describing the lichens, and subsequently it was extended to the Algæ, the Fungi and the thallose liverworts. There is no sharp limitation between a thallus and a leafy shoot.

"The external relationships of configuration of the bodies of plants are determined by the peculiarities of their living substance, the protoplasm, which in the higher plants is enclosed within the numerous cells which compose the plant; it is only among the lower plants that we find unicellular bodies. In land-plants the cellular structure is general and the several cell-chambers are separated from one another by firm walls."

Here Goebel speaks of Sachs' definition of the energid as the unit of cell structure, quoting Sachs, who says: "By an energid I mean a single nucleus with the protoplasm which it dominates." Thus he distinguishes the monergic type of plant, which is unicellular and has but a single nucleus—*i.e.*, is a single energid—and the polyergic forms which have many energids that are usually separated into individual cells by cell walls, tho in some of the lower forms they may not be.

"It has been possible," he continues, "in a large number of cases to discover a relationship between their forms and their life-functions. We see this, for example, among diatoms. The monergic cells of fixed species have a different construction from that which obtains in the actively moving or floating species. It is also clear that the pear-like form of most swarm-spores is especially favorable for their movements. In other cases, however, we know so little regarding the spe-

cial life-relationships of the plants that we are quite unable to speak with certainty. We cannot, for example, say whether the rod-like or sickle-like desmids have relationships of a kind different from those of the plate-forms.

"The degree in which the single energids are united with one another may be more or less intimate. A polyergic plant is either an energid colony or cœnobium (cellular or non-cellular), in which a division of labor between the several energids has not yet appeared and each energid is capable of living for itself, or the energids exhibit a division of labor, and, altho in unison with one another, are therein different from one another; they form an energid dominion. This is what has come to pass in the majority of the polyergic plants. There are, of course, many transitions between these two conditions, and their separation is in a measure artificial, being based upon extreme relationships.

"In the higher plants the shoot is differentiated into shoot-axis and leaf in all cases except in some degenerate parasites. There are, it is true, leafless shoots of limited growth, but these are quite exceptions. In the lower forms of plant-life such a differentiation of the shoot may also take place. The sexual generation of many liverworts and of the whole of the mosses shows an evident division into shoot-axis and leaf, and, as has been above explained, this condition is reached among the liverworts in the most different cycles of affinity, which have developed quite independently one of the other. That the leaves of the sexual generation of mosses are not homologous with those of the asexual generation of the Pteridophyta is sufficiently clear, but terminology is only a means to an end, and I have no hesitation in calling the leaf-like organs which we find in many Thallophyta 'leaves.'"

The development of morphology, both as it applies to cell and tissue structure alone and as it applies to the study of life-histories, has made rapid advances in the last few decades. There have been and are numerous keen investigators covering all morphological fields. The present knowledge of the structure of the individual cell has greatly increased, and the store of information regarding the embryology of the higher plants, tho founded on the classic work of Hofmeister, is well-nigh a new science. The study of life-histories in as complete a way as possible is now the aim of morphological investigators.

"The morphologist," says H. M. Richards, "who devotes his time to the study of life-histories is engaged in the work of tracing the race history of plants from the comparison of the individual development of more or less nearly related forms. Thus the homologies which have been traced among the flowering plants and their nearest

allies among the ferns and other forms indicate to us the probable race history of these groups. It is true that the beginning of this work dates back some decades, but it is still, to a large extent, an open field, and numerous investigators are actively prosecuting research along these lines. For example, the alternation of a sexual and non-sexual generation of plants which has long been known as characteristic of the life-histories of higher forms has recently been established among the lower groups, and thus a much clearer view of the whole series of the plant kingdom is being obtained."

The branch of botanical research known as ecology is one of the most inclusive. It may be regarded as an attempt to grasp the full meaning of the morphological and physiological manifestations of the living plant not only as they concern itself, but also in their relation to all factors of its environment, whether with other organisms or with purely physical agents. It is evident that the problem is a stupendous one, and in the present state of knowledge both of physiology and morphology it cannot be expected that necessarily permanent results are to be obtained. Nevertheless it serves a highly important end in calling attention to and insisting upon the fact that environmental factors must influence the individual; that no organism, even a plant, is a free agent in determining its career or the career of its progeny.

Ecology is the application in a broad and more philosophical way of the methods of the physiological anatomist coupled with those of the taxonomist; but, in addition, the work of the botanist touches the field of the physiographer and geologist. "Ecology," says H. M. Richards in his "Botany," "is the endeavor to uncover the plan of nature as it governs the relations of the different plant forms in a given area, to understand the why and the wherefore of the association of very different forms in one locality. The keynote of the philosophical development of this topic rests on the conception of the constant struggle of individuals or groups of individuals to maintain themselves against other forms, which leads to a balanced relation of the different species in a given flora."

From the beginning one of the greatest of ecological problems has been that of the origin and significance of adaptations. "In other days," remarks Henry C. Cowles in his "Trend of Ecological Philosophy," "the solution was sought in special creation, one of the most unscientific of all theories, because altogether subversive of experiment. The entire question was prejudged at the outset. The theory of special creation, however, has not been especially harmful, because it has generally seemed so unlikely as to have received but little support among scientific men. Perhaps the most baneful of all

ecological theories has been the Lamarckian theory of direct adaptation.

"The theory of natural selection has worked great harm in the ecological study of plant structures. Thorny plants have been supposed to be selected by reason of animal incursion, and such complex things as floral structures have been supposed to be the result of parallel selection on the part of flowers and insects. There is no adequate evidence, experimental or otherwise, for views of this character. Such experimental work as has been done appears to show that the success or failure of a plant rarely depends upon this or that little advantage, upon which natural selection may be supposed to work, but rather that its perpetuation depends for the most part upon other things than its so-called adaptations.

"Few more perfect adaptations for their function can be thought of than the digestive glands of insectivorous plants, and yet there is no evidence in support of the idea that such plants have been able to survive by reason of these glands. The evolution of such a complex flower as that of the orchid along lines that are parallel with the evolution of the mouth parts of a special insect requires a nicety of operation that seems staggering, and all the more because the flower, at least, seems to have evolved so far along the lines of zygomorphy as to be a source of disadvantage rather than of advantage, an impossible idea to the natural selectionist.

"The facts of regeneration show that plants and animals are often in a position to make an instant new reaction to conditions unlike those to which they have ever been accustomed and that these reactions may or may not be advantageous. In any case, natural selection can have no possible connection with their origin. The trend of the time, especially among botanists, is unmistakably toward the abandonment of natural selection as a theory of evolution, but ecological work is finding a dominant place for it as one of the controlling factors in succession. The student of vegetation dynamics, more perhaps than any other, finds displayed before him an incessant struggle for existence; in the changing conditions the fitness of an old species to remain or of a new species to displace it is commonly a matter of profound importance in the vegetative change produced.

"To the working ecologist the necessary consequences of the abandonment of the idea of adaptation and of natural selection as a causative factor are most vital. First and foremost there comes the possibility of disadvantageous trends in evolution. To some extent such tendencies will be checked by the destructive operation of natural selection, so that only such new species as are most fit are likely to survive and have progeny. But in view of the ideas that have generally prevailed in past years, it cannot be emphasized too strongly

that plants may retain useless structures and even structures that are moderately harmful and yet live on if they also possess other structures or habits that are sufficiently advantageous. This conception at once relieves ecologists of one of the most arduous of their former duties, the establishment of an advantageous function for every organ and of a benefit in every function."

CHAPTER VII

PHYSIOLOGY OF PLANTS

"Every living organism has the power of producing offspring which inherit the characteristics of the parent stock," says Pfeffer in his "Physiology of Plants." "The fact that the acorn always produces an oak, a fungus spore the same specific fungus, is sufficient proof that it is the inherent properties of the living substance of the embryonic organism which primarily determine the shape, character and individual peculiarities of the adult. organism. In the young plant the full development of such characters takes place only through interaction with the external world, and not unless certain necessary conditions are fulfilled. Thus, if the plant is deprived of nourishment it finally dies of hunger, while vital activity and growth are only possible in the presence of water and within certain limits of temperature. It is evident that the absence of any one of the necessary conditions must invalidate the remaining ones, so that if the amount of water is insufficient, or if the temperature sinks too low, the vital activity of the organism is depressed or completely arrested, and similarly at a high temperature death ultimately supervenes. Hence Physiology is primarily required to determine the powers and possibilities of individual organs and cells and their various interactions.

"The manifestations of life when traced back to their ultimate origin are always found to originate in the protoplasm, an undifferentiated mass of which constitutes the substance of the simplest living elementary organism. Hence one of the tasks of Physiology is to throw light on the manner in which the inherent nature of the protoplasm is responsible for the chemical and physical changes to which it gives rise. It is as impossible to picture a regular continuance of life otherwise than by the coöperation of different organs and biological elements as it is to imagine a watch which could still keep time after the removal of certain of the wheels.

"The chemical nature of the living organism, with its indissolubly connected chemical and mechanical properties, is of much greater importance than that of a machine; for in the changes which take place in the self-regulating protoplasmic mechanism chemical nature and affinities are, in all cases, of fundamental importance. Hence progress in Physiology necessarily goes hand in hand with progress in Chem-

istry. From a physiological standpoint it is hardly possible, for example, to over-estimate the importance of a complete knowledge of the chemical constitution of the proteids, which take so prominent a part in building up the living protoplast, especially in view of the possibility that each particular species may be characterized by a specific variety of living proteid.

"There is no reason for regarding life as the product of an extraordinary and mystical natural force; it is to be treated simply as a special and peculiar manifestation of energy. Moreover, since we can only guess at the evolutionary history of the organism, it is only possible for us to deal with the physiological and other properties which it now possesses, and however clearly we may be able to explain the peculiarities of a given plant as being due to characters and tendencies inherited from its parents, we shall still be unable to determine with certainty the evolutionary origin of that particular species.

"The production and hereditary transmission of variations are connected in many ways with the general physiological problems with which we are immediately concerned. When any variation takes place an alternation in the structure or nature of the protoplast must have previously occurred, provided the variation is not merely a temporarily induced one, but is one capable of hereditary transition to the offspring. This is true for the lowest as well as the highest plants, and whether the variation is perpetuated by sexual or asexual reproduction. The conclusion that a change of this kind necessarily indicates an alteration in the arrangement or character of the protoplasmic constellation is, indeed, a logical necessity, even tho it is impossible to determine exactly how the given variation arises or is induced.

"The reproduction of hybrid forms is evidently due to the combination of two different kinds of living substance. There can be no doubt that if it were possible to interchange the nuclei of two separate and distinct protoplasts, assuming that the strange nuclei and protoplasts could live and grow together, two new organisms would be produced differing from one another and from the original protoplasts. These special characteristics of the new organisms would be preserved so long as the union and coöperation between the parts of the new protoplasts were maintained. This would also be the case if, for example, a bacterium existed in intimate and permanent symbiotic union with the protoplast, as a chloroplastid does, and were transmitted from generation to generation in the ovules.

"It is, as a matter of fact, not inconceivable that the existence of certain species, as such, depends upon the protoplastic or symbiotic unions of similar character to the above. Nor is the possibility excluded that the tiny symbiont might be too small to be visible, or might be unable to continue an independent existence outside of the

protoplast. Comparatively recently lichens were regarded as distinct organisms, altho we now know that they are the products of a synthetic union of two distinct plants, and that by the artificial synthesis of various algæ and fungi new forms, or forms similar to those already known, may be produced with relative ease.

"Nevertheless, as is well known, variation capable of hereditary transmission may arise without the help of foreign protoplasm, and certain bacteria afford especially instructive examples of these. Thus in many bacteria the power of forming either spores or certain metabolic products may be inhibited by a particular mode of treatment, and in some cases this inhibition is permanent, so that even under normal cultural conditions a reversal never takes place. The variety thus produced will hence remain constant in a neutral environment, although there always remains the possibility that by the action of other agencies a return to the original condition may be induced. Accidental reversions are, as is well known, by no means uncommon in the higher plants.

"Saltatory variations often do appear in organisms, and may arise under precisely similar external conditions in particular individuals only, or may even affect these in different manner or degree. It has previously been stated that Physiology must necessarily seek an explanation of all vital processes in the developmental and formative powers of the protoplast. Our knowledge on this point is still in its infancy, and we must be content if we can gain here and there a glimpse into the internal protoplasmic mechanism. Even tho our knowledge with regard to the structure of protoplasm were to be enormously increased we should still see, not the causes and forces which are acting, but only the results which they produce. The most perfect mental picture of the plant or of the protoplast must necessarily fail to reveal the hidden and invisible causes which make it assume its specific form.

"Above all, it must be remembered that the simplest protoplast is an organism of very complex structure, and that its various activities result from the interactions of its component parts and organs. The particular result which any given cause produces is due to the special nature of the given protoplast. Every plant must therefore necessarily have certain special protoplasmic characteristics which are peculiar to it alone. At the same time, protoplasts of similar origin may temporarily or permanently acquire special properties by a progressive differentiation of labor and by adaptation to special aims and purposes. Nevertheless, the plant protoplast, so long as it remains living, retains all the general features which characterize a typical vegetable cell.

"In order to attain certain ends the organism forms parts which are not living or capable of life. One such organ is the cell-wall

which the protoplast constructs as a protective mantle in which it may live and work; indeed, the protoplast living inside its cell-wall may be compared to a snail in its shell. In certain cases the protoplasmic contents may escape from the cellulose investment as a naked swarm-spore, which later may build for itself a new domicile.

"In the protoplast, just as in a snail, the internal structure and functional importance of the component parts require to be studied. Within the protoplast are spaces having considerable functional value, which are surrounded by living substance, but whose contents are not living. Such are the vacuoles, which subserve a variety of functions. They may serve for the storage of reserve food material, while the dissolved substances which they contain give rise to the osmotic properties of the cell and preserve these properties during growth. As the vacuoles increase in size the cell becomes much larger, but the amount of protoplasm which it contains undergoes no increase, or but little, so that finally it is reduced to a thin primordial utricle or bag, closely addressed to the cell-wall, and containing a single large central vacuole. Vacuoles are laboratories in which food may often be digested or building material prepared for use, while at the same time they are utilized in translocation.

"The body of the protoplast, the protoplasm as we may call it, is built up of organs and elemental structures. The nucleus is an organ of very general importance, and, indeed, a separation into nucleoplasm (karyoplasm) and cytoplasm probably occurs in all protoplasts. On the other hand, chromatophores, including chlorophyll corpuscles, are organs of special character and are absent from fungi. When such special organs are present they may be given the general name of plastids.

"Like all living substance, the plasmatic organs are of considerable complexity. This is readily perceptible in the resting nucleus, and is admirably shown when the latter divides; while the chromatin fibers, which are then so markedly visible, may also be seen to have a definite structure of their own. Besides the plastids already mentioned, the cytoplasm may contain minute bodies, often in great numbers, which, regardless of their morphological and physiological nature, may be termed microsomes or microsomata. They may be composed in some cases of non-living substance, but in other cases may be minute living plastids.

"In a small cell, or one of the organs of such a cell, the component units must necessarily be still smaller, and yet have positive dimensions; while the smaller and more numerous these units are the more varied and complicated will the possible combinations be. At the same time a relatively greater surface area is correlated with the smaller size, and this is a factor of the utmost importance; for bacteria teach us what remarkable powers are conferred by extrem

minuteness and what extraordinary processes it renders such organisms capable of performing.

"The various operations which are continually going on in the body of the plant involve the execution of a considerable amount of work. This is very evident in the enormous development of a large tree from the relatively small seed. Such a process of construction has involved the preparation of a vast quantity of highly complex material from very simple chemical substances. The processes incident to life also, tho they may not lead directly to the formation of such substances, cannot be conducted without involving a considerable amount of work, whether the plant is a minute body consisting of a single protoplast, or an organism of a much higher degree of complexity."

"If we turn now to consider the sources of the plant's energy," continues J. Reynolds Green in his "Introduction to Vegetable Physiology," "it is evident that they must be in the first instance of external origin. . . . The radiant energy of the sun, indeed, is the only possible source which can supply it to normal green plants. The rays which emanate from the sun are generally alluded to as falling into three categories: those of the visible spectrum, those of the infra-red, and those of the ultra-violet. The second of these are frequently spoken of as heat rays and the last as chemical.

"The greatest absorption of energy appears to take place in consequence of the peculiarities of chlorophyll. This substance, whether in the plant or when in solution in various media, absorbs a large number of rays in the red and in the blue and violet regions of the spectrum, together with a few others in the yellow and the green. The solar spectrum, after the light has passed through a solution of chlorophyll, is seen to be robbed of rays in these regions, and hence to present the appearance of a band of the different colors crossed by several dark bands. The greater part of the energy so obtained in the cells which contain the chloroplasts is at once expended, partly in constructing carbohydrate food materials and partly in evaporating the water of transpiration, the latter process being much the more expensive."

Speaking of these carbohydrate food materials, H. M. Richard says: "It is evident that the starch, which is the first substance that we readily recognize, is not the first substance which is formed. Modern research points more and more to the conclusion that it is the simplest of carbohydrates that is produced, a substance known as formaldehyde. But what is especially interesting is that it seems not impossible that this primal reaction may not, after all, be a function of the living protplasm, but a chemical reaction that can be carried on outside the cell through the agency of chlorophyll. It is in the further elaboration of this first substance formed that the living protoplasm is apparently necessary. At any rate, we know that the energy de-

manded for the process must be afforded by the particular rays of sunlight which the chlorophyll absorbs."

"There is plenty of evidence," continues Green, "of the power of plants to avail themselves of the heat rays. Not only can the air rob the plant of heat by radiation, but when its own temperature is high it can communicate heat to it in turn. Indeed, its absorption by the leaves would be a source of considerable danger to the plant were it not for the cooling effect of transpiration, which dissipates 98 per cent. of it during bright sunshine. No doubt this dissipation is one of the chief benefits secured by transpiration.

"It is evident, however, that in the general economy of the plant something further must be at work in connection with the supply of energy. The absorption of these external forms must take place at the exterior of the plant, while many of the processes of expenditure are carried out in parts which are more or less deep-seated. We are obliged to turn our attention, therefore, in this connection as in that of the construction and utilization of food, to processes of accumulation, distribution and economy.

"What is the immediate fate of the energy absorbed? It enters the plant in what is known as the kinetic form. A very considerable part of the kinetic energy of the sun's rays, we have already seen, is devoted at once to the evaporation of the water of transpiration, but some of it is employed by the chloroplasts to construct some form of carbohydrate. The energy so applied can be again set free by the decomposition of this formed material. If the latter were burned its combustion would be attended by the evolution of a certain definite amount of heat. This heat would represent the energy that had been applied to the construction of the material so burned. Any accumulation of material in the body of the plant represents, therefore, not only a gain of weight or substance, but a storage of energy. This has disappeared from observation during the constructive processes, but can be liberated again during their decomposition and applied to other purposes. Energy which has thus been accumulated and stored is known as potential energy, to distinguish it from the actual or kinetic energy originally absorbed. The formation of material in the plant, therefore, involves a storage of energy in the potential form, and wherever such material is found there is in it an amount of energy which can be liberated with a view to utilization at any point to which the material has been transferred.

"The protoplasm itself contains a store of such potential energy. It can only be constructed at the expense of food supplied to it. The formation of the protoplasm which follows the supply of food to the cell involves work, and the energy so used is partly changed from the kinetic to the potential condition. When the protoplasm undergoes

what we have called its self-decomposition, which is continually taking place, a certain amount of this potential energy is liberated and can be observed and measured in various ways. When destructive metabolism is active there is usually a rise of temperature, as in the processes of the germination of seeds. A certain amount of the liberated potential energy in this case manifests itself in the form of heat. A vegetable cell which obtains no direct radiant energy from without can, consequently, obtain the energy it needs from within itself by setting up decomposition, either of its own substance or of certain materials which have been accumulated within it.

"The transformation of potential into kinetic energy is associated with decomposition just as the converse process is bound up with construction. Destructive metabolism in the cell is then the means by which its energy is made available. The processes of this katabolism go on in the interior of each cell. Each liberates at least as much energy as it requires for the maintenance of its life and the discharge of particular functions. The processes associated with the utilization of the stored energy are, then, chemical decompositions in which various constituents of the cell are involved. These are of two kinds, in the first of which the protoplasm itself takes part, and which comprize the processes in which its own breaking down takes place; in the second it effects the splitting up of other bodies without a necessary disruption of its own molecules.

"Respiration is to be looked upon as a process very largely connected with the utilization of the store of energy which each cell possesses, and perhaps primarily to be concerned in the transformation of that energy from the potential to the kinetic form. The oxygen appears to be necessary mainly for the purpose of exciting those decompositions of the protoplasm which are so dependent upon its instability."

CHAPTER VIII

GROWTH AND VARIATION

"IN studying the growth of plants," says Reynolds Green, "the relation which it bears to the processes of metabolism must be borne in mind. The constructive processes are much greater than those which lead to the disappearance of material from the plant-body. The result of this is that there is a conspicuous increase in the substance of the plant as well as an accumulation of potential energy which can be made use of by the plant through various decompositions which its protoplasm can set up. The great permanent accumulation of material is what we associate with the processes of growth. Mere increase in weight in an organ does not, on the other hand, necessarily imply any growth.

"Growth," he continues, "is in the strict sense always associated with the formation of new living substance, and is very generally accompanied or immediately followed by additions to the framework of the growing cells or organs. It is in nearly all cases attended by a permanent change of form. This is perhaps not so evident in the case of axial organs as it is in that of leaves and their modifications, tho even in them it can be detected to a certain extent. It is much more conspicuous in the case of leaves, for the latter, as they expand from the bud, have usually a different shape from that of the adult ones, and the assumption of the mature form is a gradual process, taking place as the age of the leaf increases. Growth may, in the light of the considerations just advanced, be defined as permanent increase of bulk, attended by permanent change of form.

"Growth in the lowliest plants may be coextensive with the plant-body. In all plants of any considerable size, however, it is localized in particular regions, and in them it is associated with the formation of new protoplasts. In the sporophytes of all the higher plants there exist certain regions in which the cells are merismatic; that is, which have the power of cell multiplication by means of division. In such regions, when a cell has reached a certain size, which varies with the individual, it divides into two, each of which increases to the original dimensions and then divides again. As these growing regions consist of cells, the growth of the entire organ or plant will depend on the be-

havior of the cells or protoplasts of which its merismatic tissues are composed.

"The growth of such a cell will be found to depend mainly upon five conditions: (1) There must be a supply of nutritive or plastic materials, at the expense of which the increase of its protoplasm can take place, and which supply the needed potential energy. (2) There must be a supply of water to such an extent as to set up a certain hydrostatic pressure in the cell. (3) The supply of water must be associated with the formation of osmotic substances in the cell or it cannot be made to enter it. In the absence of the turgescence which will be the result of the last two conditions no growth is possible, for reasons that will presently appear. (4) The cell must have a certain temperature, for the activity of a protoplast is only possible within particular limits, which differ in the cases of different plants. (5) There must be a supply of oxygen to the growing cell, for, as we have seen, the protoplast is dependent upon this gas for the performance of its vital functions, and particularly for the liberation of the energy which is demanded in the constructive processes. This is evident also from the consideration that the growth of the cells is attended by the growth in surface of the cell-wall; and as the latter is a secretion from the protoplasm—a product, that is, of its katabolic activity—such a decomposition cannot readily take place unless oxygen is admitted to it.

"Growth, so far as it implies only the formation of living substance, is thus a constructive process. It is, however, intimately associated with destructive metabolism or katabolism, the latter being involved in the construction of the increased bulk of the framework of the cell or cells, and being essential to supply the energy needed for the constructive processes.

"The process of the growth of a cell is limited in its extent, tho the limits vary widely in different cases. In some, cells grow only to a few times their original dimensions; in others they may attain a very considerable size. In any case, however, we can notice that the rate of growth varies regularly throughout the process; it begins slowly, increases to a maximum, and then becomes gradually slower till it stops. The time during which these regular changes in the rate can be observed is generally spoken of as the grand period of growth."

Closely connected with the metabolic activities of the plant in the release of energy for life processes is the phenomenon of digestion. In the simplest conception digestion means merely the rendering soluble and assimilable of insoluble food substances; but the active agents of digestion—the enzymes—may, and in all likelihood do, have a far more intimate connection with the life of the cell than the mere

preparation for absorption of food exterior to the actual living substance.

"The process of digestion in plants," continues Green, "is chiefly intracellular, and takes place in all cells in which reserve materials occur. It is only occasionally that it is found taking place on the exterior of the plant; that is, not in the interior of a cell. In a few cases it is carried on in connection with the absorption of nitrogenous or protein food, as has been already shown. Digestion, tho most generally associated in plants with the utilization of reserve materials, may thus occasionally be met with in connection with the absorption of food from without, when it is a process precisely similar to the digestive processes of the higher animals, tho it is somewhat simpler in the details of its mechanism. The intracellular digestion of plants agrees very closely with that of many of the humbler animals, and corresponds also with such processes in the higher forms as the utilization of the glycogen of the liver and the fat of various regions.

"Absorption of food from without, after preliminary digestion, is much more frequently observed when we study the nutritive processes of the Fungi. Not only protein, but also carbohydrate and fatty substances are thus digested outside the body of the plant, and the products of the digestion are subsequently absorbed.

"The protoplasm of the cell, among its many properties, no doubt has the power of setting up these decompositions, and probably in many of the very lowly plants, in which the whole organism consists of only a few protoplasts or perhaps a single one, the work is altogether effected by its instrumentality. The protoplast, in fact, carries out all the various processes of life by the interactions of its own living substance with the materials absorbed by it, aided in the constructive processes by the chlorophyll apparatus, if it possesses one. In such a protoplast we may observe at times the storage of such a reserve material as starch, and its digestion at the appropriate period.

"Even in more complex plants it is certain that the living substance of every protoplast is in a constant state of change, initiating many decompositions in which its own substance takes part, as well as others into the course of which it does not itself enter. Among these decompositions we must include the various intracellular digestive processes. Tho all protoplasm has this power, it is not usual in plants, any more than in animals, to find it exclusively relying on it. The work of digestion, at any rate, is generally carried out by peculiar substances which it forms or secretes for the purpose. We have in plants a large number of these secretions, which are known as enzymes, or soluble ferments.

"The action of these enzymes is not at all completely understood. They appear not to enter into the composition of the substances

which are formed by their activity, and they seem to be capable of carrying out an almost indefinite amount of such work without being used up in the process. They are inactive at very low temperatures, but effect the decompositions they set up freely at the ordinary temperature of the plant. As the temperature at which they are working is raised their activity increases up to a certain point, which varies slightly for each enzyme, and is called its optimum. This usually ranges between 30° and 45° C. If the temperature is raised above the optimum point the enzyme becomes less and less active as it rises, and at about 60-70° C. it is destroyed. The exact point, however, varies a good deal in the cases of different enzymes.

"Enzymes work most advantageously in darkness or in a very subdued light; if they are exposed to bright sunshine they are gradually decomposed, the violet and ultra-violet rays being apparently most powerful in effecting their destruction. They are often injuriously affected by neutral salts, alkalies or acids, tho in this respect there exists considerable diversity throughout the group.

"The enzymes are manufactured by the protoplasm of the various cells in which they occur, being produced from its own substance in a manner somewhat similar to that of the formation of the cell-wall. Usually their presence is accompanied by a marked granularity of the protoplasm, due to the formation in it of an antecedent substance known as a zymogen, which is readily converted into the enzyme. This granularity does not, however, always occur, tho we have reason to suppose that the secretion of the enzyme always takes place by successive stages. The zymogen has not, however, been definitely detected in all cases."

While, as has been stated, the digestion of substances within the cell is the most common occurrence, there are not a few cases, even among the highly developed plants, where digestive ferments are excreted and act upon materials exterior to the cell itself. The absorption of food material stored in the seed is often an instance of this, but more strikingly is it seen in the so-called carnivorous plants, such as the sundew, etc., that were so carefully investigated by Darwin. In the latter case these plants can actually utilize the available nitrogenous material presented in the form of animal substance; in short, meat.

This process of extracellular digestion is, however, more especially the attribute of the strictly parasitic or saprophytic plants, notably the lower fungi and the bacteria. Of necessity they must digest from the substratum on which they grow the necessary food material, unless it happens to be presented to them in soluble and diffusible form, a circumstance of rare occurrence. The Bacteria are the most important as well as familiar of such plants, and as producers of enormously vigorous fermentation for their size there are

no organisms which approach them. Their fermentative power has long been made use of in many industries, and at the present time is the especial study of preventive medicine in endeavoring to fully understand and guard against the deleterious effects of disease-breeding bacteria on the human organism. Associated with bacteria, in a purely physiological sense, and no other, are the highly degenerate fungi known as yeasts, the power of which in producing extra-cellular alcoholic fermentation has been known in a purely empirical way since prehistoric times.

Ptomaines, toxins, indeed some of the poisons associated with so-called toadstools and snake venoms, are all enzymatic or fermentative in their nature, and a very small quantity of them is capable of producing relatively enormous changes in the substances on which they act, and come under the general physical class of catalytic agents. The present aim of bacteriological research, as applied to disease organisms, is to discover the best mode of combating the toxins, and that has been found in the antitoxins, which have the power of uniting the toxins and rendering them harmless, altho it must be said that the manner in which they do this is not fully understood.

The study of all classes of enzymatic substances in the living organism, plants as well as animals, is at present the field which promises more than any other to elucidate the mysteries of life processes, and with the aid of modern physical chemistry the next few decades may mark a striking advance in man's knowledge of what living protoplasm really consists.

"The life of every plant is of limited duration," to quote from the Text Book of Botany by Strasburger, Nott, Schenck and Karsten. "Death ensues sooner or later, and the decayed remains form a part of the surface soil. All existing vegetable life owes its existence to the capacity inherent in all organisms of reproducing their kind. Reproduction is accordingly a vital power which must be exercized by every existing plant species. It is also evident from the very nature of reproduction that in the production of new organisms a process of rejuvenation continually is being carried on. The descendants commence their development at a stage long since passed over by parents.

"The physiological significance of sexual reproduction is not at once apparent. In many plants the vegetative mode of reproduction is sufficient to secure the necessary multiplication of the species, so that plants are able to continue without sexual reproduction. Since monogenetic reproduction is sufficient for the preservation of the species, sexual reproduction must answer some purpose not attained by the vegetative mode of multiplication, for otherwise it would be altogether superfluous that the same plant, in addition to the vege-

tative, should also possess the sexual form of reproduction, which is so much more complicated and less certain.

"What makes digenetic reproduction essentially different from monogenetic is the union of the substances of the parents and the consequent transmission and blending of the paternal and maternal properties. It is in this qualitative influence that the chief difference between sexual and vegetative reproduction is shown. And this may be regarded as the special advantage of sexuality. By vegetative reproduction the quantitative multiplication of the individual is secured, while by sexual reproduction a qualitative influence is exerted. The vegetatively produced progeny consist of unmixed descendants; the sexually produced offspring, on the other hand, are the result of a blending of the parents.

"In vegetative multiplication the complex of properties unfolded in the descendants does not, as a rule, differ from that possessed by the parent form. The sexually produced offspring, on the other hand, endowed with the properties of the father, can never be identical with the mother plant, but possess the properties of both parents. When these are divergent they frequently play very different parts in the descendants, some (dominant) characters appearing conspicuously, while others (recessive characters) become less marked or remain completely latent. In this way the descendants do not exhibit a uniform mean between the parents, but some may resemble the father, others the mother. These relations determine the character of the sexually produced descendants. Variations appearing in single individuals will, unless they are of an absolutely dominating character, become modified and ultimately lost by crossing with ordinary individuals. In such a case sexual reproduction tends to maintain the constancy of the species. In other cases, as when one parent possesses new and dominant characters, or when both parents tend to vary in the same direction, the deviation from the ancestral form may be maintained or increased by sexual reproduction.

"The great tendency to variation commonly exhibited by hybrids illustrates how the equilibrium of the complex properties of a sexually produced individual is affected by divergent parental tendencies. But even as a result of ordinary fertilization not only small and readily disappearing variations (fluctuating variations) but sometimes more striking ones occur, in which the offspring differs so strongly from the parents in characters which can be inherited that it appears to be a new species or sub-species. In such sudden variations (the occurrence of which Von Kölliker, and with him Korschinsky, term heterogenesis, while De Vries more recently calls it mutation) these authors seek the starting points of the origin of new species. This would occur when a particular species passes,

from unknown causes, into a period of mutation such as De Vries demonstrated experimentally in Œnothera Lamarckiana. The fluctuating variations which largely determine the valuable characters of economic plants—*e.g.*, the high percentage of sugar in the Sugar Beet—are in contrast to the mutations not fixed on inheritance. Careful and continued selection of the varying progeny is thus necessary to maintain the required standard of the race."

Hugo de Vries himself says, in writing on this matter of variability: "Before Darwin, little was known concerning the phenomena of variability. The fact that hardly two leaves on a tree were exactly the same could not escape observation; small deviations of the same kind were met with everywhere, among individuals as well as among the organs of the same plant.

"Darwin was the first to take a broad survey of the whole range of variations in the animal and vegetable kingdoms. His theory of Natural Selection is based on the fact of variability. His main argument is that the most striking and most highly adapted modifications may be acquired by successive variations. The direction of the adaptations will be determined by the needs in the struggle for life, and natural selection will simply exclude all such changes as occur on opposite or deviating lines. In this way it is not variability itself which is called upon to explain beautiful adaptations, but it is quite sufficient to suppose that natural selection has operated during long periods in the same way. Eventually, all acquired characters being transmitted together would appear to us as if they had been simultaneously developed.

"Correlations must play a large part in such special evolutions. Darwin repeatedly laid great stress on this view, altho a definite proof of its correctness could not be given in his time. Such proof requires the direct observation of a mutation. . . . The new evening primroses which have sprung up in my garden from the old form of Œnothera Lamarckiana, and which have evidently been derived from it, in each case by a single mutation, do not differ from their parent species in one character only, but in almost all their organs and qualities.

"Some authors have tried to show that the theory of mutation is opposed to Darwin's views, but this is erroneous. On the contrary, it is in fullest harmony with the great principle laid down by Darwin. In order to be acted upon by that complex of environmental forces which Darwin has called natural selection the changes must obviously first be there. The manner in which they are produced is of secondary importance, and has hardly any bearing on the theory of descent with modification.

"A critical survey of all the facts of variability of plants, in nature as well as under cultivation, has led me to the conviction that Dar-

win was right in stating that those rare beneficial variations which from time to time happen to arise—the so called mutations—are the real source of progress in the whole realm of the organic world.

"The origin of new species, which is in part the effect of mutability, is, however, due mainly to natural selection. Mutability provides the new characters and new elementary species. Natural selection, on the other hand, decides what is to live and what to die. Mutability seems to be free, and not restricted to previously determined lines. Selection, however, may take place along the same lines in the course of long geological epochs, thus directing the development of large branches of the animal and vegetable kingdoms. In natural selection it is evident that nutrition and environment are the main factors. But it is probable that while nutrition may be one of the main causes of mutability, environment may play the chief part in the decision ascribed to natural selection."

Dr. Daniel T. MacDougal in a lecture published in 1905 tells u that "scattered through the literature of botany and horticulture the last century are scores of records of the sudden appearanc sports and forms of the aspect of species which fully support the conclusions drawn from the observations on the evening p roses. An examination of the facts, easily brought together, all us to see that certain general principles in the organization of plant, and in its behavior in these breaks or saltations in here may be made out.

"The first and most important of these is one which was advanc by De Vries speculatively, before he began his experiments in hered ity—namely, that the plant is essentially a complex group of indivisible unit-characters. These unit-characters may not always be expressed or recognizable in external anatomical characters, since they may be in a latent condition or totally inactive.

"Popular belief in the influence of environment and the inheritance of acquired characters finds its commonest expression in 'that plants have been changed by cultivation.' Domesticated races are spoken of as 'garden forms' by botanists and horticulturists, with the implication that they are specialized types resulting from the effects of tillage. Now, so far as actual cultivation is concerned, this assumption is without foundation, since at the present time no evidence exists to show that the farm, garden or nursery has ever produced alterations which were strictly and continuously inheritable, or were present, except under environic conditions similar to those by which the alterations were produced, altho vague statements and erroneous generalizations to the contrary are current. It is true, of course, that structural and physiological changes may be induced in a strain of plants in any generation, which may persist in a share to the second, or even in some degree to a third, but no longer. Some very im-

portant operations of the market gardener and the farmer are dependent upon this fact."

"The matter of general scientific agriculture opens an immense field," says H. M. Richards. "The scientific care of our forests, for trees may be regarded as a crop, and their culture agriculture, is a question to which we, in this country, are awakening none too soon. Forestry, as practiced in Europe, demanding as it does expert botanical knowledge, perhaps not by the foresters themselves but by those who direct their labors, has saved what were the fast diminishing wooded areas."

"The scientific rotation of crops, the use of fertilizers, and the study of the physical and chemical condition of the soil in connection with the living plants," continues Professor Richards, "involve certain questions which may mean the success or failure of much farming. These questions can only be settled by careful investigations which take into consideration the nature of the plants themselves as well as the physical conditions of their environment. Some may say knowledge along this line has been satisfactorily handed down father to son; that the farmer knows his business better than the scientist; but it is a patent fact that this is not so. For instance, many a farm which has been damaged for a long period of years by the overliming of the soil might have been spared had the farmer of fifty years ago had the knowledge which we now have of relation of lime to the other mineral substances needed by the plant, of when to apply it and when to withhold it. It is the difference between merely empirical knowledge and that which is based on scientific principles.

"When the contest comes between virgin soil and long-tilled land, the latter, no matter how rich it may once have been, must needs be cultivated more intensively if it is to hold its own. Intensive cultivation requires the aid of special information, and it is here that scientific agriculture comes into play. Few people realize that without artificial fertilizers, the direct outcome of highly theoretical work on the raw foodstuffs of plants, much of the farming of to-day would be almost impossible; and the proper use of fertilizers is but one of many questions.

"We are coming now, in this country, to a stage in its development when scientific agriculture must be seriously considered. Fortunately, it is being considered, and the federal and State establishments devoted to the investigation of these agricultural questions may confidently be expected, I think, to help in the solving of the practical economic questions that must arise in the competition of our own agriculture with that of other lands. The way it must be done is by the introduction of improved methods, based on carefully

conducted scientific research, that often find their stimulus in the highly theoretical investigations of the pure scientists. Thus must the so-called impractical devotee of science come in contact with the practical man of affairs, and furnish him knowledge that can be used for the benefit of all."

ASTRONOMY

INTRODUCTION

In the present volume there have been covered in a comprehensive and popular manner the various departments of Astronomy. Owing to its treatment in a definitely historical and descriptive manner, however, it may be possible to supplement the general review by a few brief statements of some of the results and problems that confront us in the actual work of the observational astronomy of to-day.

There is frequently brought before the astronomer the fact that certain subjects that were apparently exhausted have proved through the more advanced methods of to-day, or perhaps by chance, to be veritable mines of discovery, richer by far than had been anticipated in all the previous investigations. A remarkable illustration of this fact is the splendid work of Professor Hale at the Solar Observatory of the Carnegie Institution at Mount Wilson, California. The Sun had almost been relegated to that limbo from which nothing new can ever come. With the exception of Hale's development of the spectroheliograph, which made possible the continuous photographic study of the surface of the Sun and of the solar prominences, but little advance had been made in solar research for a very long period. Even with the new instrument the work seemed to be confined to the photography of the prominences and a few other features of the Sun that were already observable visually with the spectroscope. Before this the Sun was somewhat of a curiosity and but little new information was had concerning it. It only became really interesting when a total eclipse was imminent, at which time the corona could be seen and studied. The spectroheliograph was the first great step in the study of the Sun. Even though this made possible a continuous photographic record of the prominences and kindred features it could not record the more attenuated and delicate corona. Indeed, we seem to-day as far as ever from any sight of this mysterious object without the aid of the friendly Moon, which for a few minutes at long intervals hides the Sun and gives us our only view of the corona.

But the great work done by Professor Hale and his associates at Mount Wilson (which was foreshadowed by his work at the Yerkes Observatory) in the discovery of the solar vortices and

magnetic fields of sun-spots has revolutionized the study of that body and opened up new fields of investigation in this direction that are almost unlimited.

Mr. Abbot, of the Smithsonian Institution, has also established a permanent station at Mount Wilson for the investigation of the solar constant and a general study of the heat of the Sun. The solar investigations, therefore, that are going on at Mount Wilson are among the most important that have ever been undertaken. They are not only of the highest interest, but may ultimately lead to important results bearing upon the commercial life of the world by revealing to us some possible means of forecasting conditions upon the Earth. Any vagaries in the Sun must have more or less influence on the conditions of the Earth which owes its every throb of life to the mighty influence of the Sun.

Much of the ordinary spectroscopic work may be said to be in its infancy because of the vast fields of research that are open to it. It is already laying the foundation for a very accurate determination of the distance of the visible binary stars where both stars can be observed with the spectroscope—an accuracy that can never be attained by the ordinary methods of parallax work. Already this has given results of precision in the case of Alpha Centauri, whose distance has been determined by Professor Wright, of the Lick Observatory, from spectroscopic observations combined with the known orbit of the star. Time, however, is an element in this work, and after a sufficiently long interval a valuable harvest of knowledge of star distances will result. The spectroscopic material for such investigations is being specially obtained by Professor Frost and his associates at the Yerkes Observatory (as well as by others elsewhere), where spectrograms of the various visual binaries that are bright enough to give a measurable spectrum are being carefully and accurately accumulated. A possible improvement of the spectroscope, whereby a larger percentage of the light can be utilized, will make possible the extension of this class of work, for at least 90 per cent. of the available light cannot at present be utilized. If this can be done, the efficiency of the spectroscope will be vastly increased and a great number of objects at present beyond the reach of accurate spectroscopic study will be investigated and their nature and physical conditions become known. A step in this direction is the erection on Mount Wilson of a reflecting telescope one hundred inches in diameter. The great light-grasping power of this instrument enables much fainter objects to be studied than could be observed with the means available prior to 1916.

Only a few years ago our knowledge of comets seemed to be satisfactory. What we could see with the naked eye or with the telescope apparently readily agreed with certain theories that were formulated

to explain them. The tails of various comets were sorted out and assigned to different classes. This one was a hydrocarbon tail and that a hydrogen tail, etc. The spectroscope had shown that comets in general consisted of some form of hydro-carbon gas (such as cyanogen). Such gas or gases are evidently mixed up with minutely divided matter which is disrupted and expelled from the comet's head and thrown out backward from the comet away from the Sun. This was shown later by the experiments of Lebedew, Nichols and Hull to be due to the pressure of the Sun's light upon the smaller particles of the comet, which drove them away into space with increasing velocity to form the tail. The simple phenomena thus seen by the eye were rather easy of explanation. Photography, however, has revealed such a mass of strange phenomena in these bodies that the theories which seemed so satisfactory before are now seriously questioned, and some of them appear to be entirely inadequate to explain some of the phenomena shown by the photographic plates. But little indication of many of the most extraordinary changes and peculiarities of comets' tails is seen by the eye. In part this is due to the fact that much of the light of a comet is of a nature that has but little effect on the human eye, though it is peculiarly strong in its action on the photographic plate. The first of these bodies to exhibit these peculiarities was Comet IV, 1893 (Brooks). Some of the phenomena of its tail, as revealed on the photographs, appeared to defy the ordinary theories and seemed to show that an influence outside that of the direct action of the Sun upon the comet had manifested itself in the distortion and breaking of the tail. The scarcity of active comets in the succeeding years left this question in abeyance. Comet C, 1903 (Borrelly), however, gave us much information as to the actual velocity of the outgoing particles of the tail, some of which receded from the comet at the rate of 29 miles a second. This object also quite clearly showed that a seat of force of great activity existed in the comet itself, which enabled it to shoot out streams of matter at large angles to the main direction of the tail, which were apparently not bent or affected by the pressure of the Sun's light. The phenomena of Comet IV, 1893, were repeated in Comet C, 1908 (Morehouse). But a great amount of new phenomena was also shown by this last body which demands still greater changes in our ideas of comets and their tails. This object is so recent and its phenomena so startling that astronomers have not yet had time to thoroughly discuss the vast amount of material that exists for its study. Briefly, added to the already known rapid changes in the tail of a comet, this object exhibited the most extraordinary freaks. Tails were repeatedly formed and discarded to drift out bodily in space until they finally melted away. In several cases the tail was

twisted or corkscrew shaped, as if it had gone out in a more or less spiral form. Areas of material connected with the tail would become visible at some distance from the head, where apparently no supply had reached it from the nucleus. Several times the matter of the tail was accelerated perpendicularly to its length. At one time the entire tail was thrown forward and violently curved perpendicularly to the radius vector in the general direction of the sweep of the tail through space. This peculiarity is opposed to the laws of gravitation. There is no known cause for this freak of the tail. Evidently we have here, and in many other of the phenomena of this body, some unknown influence at work in the planetary spaces. What this is, is one of the great problems for the future to solve. It has been suggested that many of the unaccountable phenomena of this comet are electrical and can be attributed to the same influence that produces our magnetic storms and auroras on the Earth, and these are believed to be due to abnormal disturbances on the Sun. Halley's comet on its last return was a disappointment, adding little to the solution of this problem.

The study of the dark or apparently vacant regions of the sky, especially the Milky Way, is of paramount importance. The photographic plate has shown that the dark regions (the so-called "coal-sacks") are generally connected with masses of nebulosity of gaseous matter. These are especially remarkable in the regions of the stars Theta Ophiuchi and Rho Ophiuchi. In the latter case we find a magnificent nebula in a rich region of the Milky Way occupying a hole that is apparently devoid of stars. Some astronomers have attributed the general absence of stars here to absorbing matter—to an opacity and partial dying out of the nebula that cuts off the light of the stars which are beyond it. What these apparent vacant regions really are is, therefore, an unsolved problem at present. Some of them are evidently due to the thinning out and actual absence of stars in those parts of the sky. But the others, which are connected with nebulosities, seemingly must have some other explanation. One fact appears to be brought out by the great nebula of Rho Ophiuchi is that the groundwork of the Milky Way in this region, and by inference elsewhere, may be made up of stars actually much smaller than the average of those seen in the general sky. If this were so it would materially change our ideas of the Milky Way. This supposition comes from the fact that the great nebula is connected with some of the brighter stars in this region, while at the same time there is apparently evidence that it is connected with the faint stars that form the groundwork of the Milky Way here. If, however, the dark regions about and near the nebula are due to the absorption of light by an opacity of the nebula, the supposition as to the relative sizes would not

hold, for the nebula in that case might be nearer to us than the Milky Way. The nebulous region near Omicron Persei with a 6 hrs. 41 min. exposure on a 10-inch telescope gave results adding to the importance of the opaque nebula theory.

The great nebulous regions of the sky that photography has revealed to us are intimately connected with the Milky Way. They cover very large regions of the heavens and must be almost inconceivably great. In no case has it been possible to determine the exact dimensions of these wonderful objects, because we do not know their distances. It is possible, however, by assumptions that are justified by facts to arrive at some idea of their minimum extent. If they are no further away than the nearest fixed stars, and from their evident connection with certain stars we know that they must be much further away, we can form some idea of their vastness. Our own Sun if removed to the distance of the nearest fixed stars would present an apparent diameter of about the hundredth part of a second of arc. Its known diameter is something like a million miles (accurately 867,000 miles). Some of these nebulous regions are many degrees in diameter. The one connected with the Pleiades is ten degrees in diameter. It is certainly connected with the cluster whose distance is much beyond the nearest fixed stars. From this it will be readily seen that this great nebulous region must be at least some four million times greater in diameter than our Sun, or over one hundred thousand times greater than the entire diameter of our known solar system. These are figures that appear to be appallingly great. But they are only relatively so and only shock us because the facts are new and we are not yet used to them.

What is the ultimate function of these enormous masses of gaseous matter that we find lying in space? Are we sure that they are the primitive matter from which worlds and systems are finally to be evolved? These, very briefly, are a few of the problems that we encounter in astronomy as developed by the subtle means of research in use at the present time.

E. E. Barnard.

ASTRONOMY

CHAPTER I

THE GROWTH OF ASTRONOMICAL IDEAS

HERBERT SPENCER has stated that evolution is a change from the indefinite to the definite, from the incoherent to the coherent. If any proof of that doctrine were required, it would assuredly be found in the development of astronomical conceptions. In this chapter an attempt will be made to outline in a general way the manner in which the present theories were evolved from the mysticism of folk-lore and religion. Some of the matter herein presented is drawn from Arrhenius' "Die Vorstellung von Weltgebäude im Wandel der Zeiten."

The astronomical beliefs of prehistoric man were no doubt similar to those entertained by the Eskimo of the Arctic regions, and the untutored tribes of Argentine Republic, South Africa and Australia, tribes who, living only for the day, concern themselves but little with to-morrow and yesterday and care nothing about the universe.

Somewhat more cultured than these Eskimo and South American and South African tribes are primitive nations who have endeavored to account for the origin of the Earth and the heavens by anthropomorphic theories. The universe must have been created by some Personal Being who had at his disposal something to mold. The idea that the universe was made out of nothing is a philosophical assumption which was introduced by the highly cultured philosophers of the East. The something out of which the universe was created is usually regarded as water, an element which to the eye at least is perfectly homogeneous, shapeless, and chaotic. That the fertilizing mud was deposited by floods must have attracted the attention of ancient primitive races, for which reason they may have assumed that all the Earth was slowly and gradually deposited from water. Thus we find that Thales (550 B.C.) argued that all things were created from water. Yet other substances were assumed as primordial matter, and later Anaximines of Miletus, who also flourished in the sixth century, called the generative principle of things air or breath, while Hera-

clitus, who flourished at Ephesus near the end of the sixth century, believed that all bodies were transformations of one and the same element, which he called fire.

The belief that primordial water is the origin of all things was deeply rooted in Asiatic races, for it occurs over and over again in many creation myths, among others in the Chaldean and in the Hebrew. Instead of water we sometimes find that an egg may be taken as the primal unit, no doubt because every organism springs from an apparently lifeless seed. Thus we find that the egg plays a most important part in the creation myths of the Japanese as well as in narratives from India, China, Polynesia, Finland, Egypt and Phenicia.

In many of these creation myths, of which I. Riem has collected no fewer than sixty-eight, more or less independent of one another, deluges are prominent features. In nearly all of them it is supposed that after the water subsided the land was exposed, fertilized and made to bring forth.

All of these creation myths are interwoven and interconnected with religious belief. To the savage mind everything that moves is endowed with a Spirit. Accordingly primitive man endeavors to propitiate the Spirit by magic, knowledge of which art is given only to the medicine man or to the priest. In a certain sense, therefore, magic is the precursor of natural science, and the myths and lore upon which the practice of magic is based are remotely antecedent to our scientific theories. According to Andrew Lang, myths are based as much upon primitive science, resting upon superstition, as upon primitive religious conceptions.

In Maspero's "Histoire Ancienne des Peuples de l'Orient Classique" we find an account of the Chaldean conception of the universe. Surrounded on all sides by the ocean, the Earth rises in the middle like a high mountain whose summit is covered with snow from which the Euphrates springs. The Earth is encircled by a high wall, and the abyss between the Earth and the wall is filled by the ocean. Beyond it is the abode of the immortals. The wall supports the vault of the firmament, shaped by Marduk, the Sun God, out of a hard metal, which shines in the daytime but which at night is like a blue bell set with stars. In the morning the Sun enters the vault by an eastern entrance and at night makes its exit by a western outlet. Marduk arranged the year according to the course of the Sun and divided it into twelve months, each of which counted three periods of ten days. The year, therefore, numbered three hundred and sixty days. Every sixth year a special month was intercalated, so that the year had on an average three hundred and sixty-five days.

As the lives of the Chaldeans were to a high degree influenced

by a change in the seasons, they laid great stress upon division of time. In the beginning they probably based their chronology upon the movements of the Moon, like many another race. Soon they recognized that the Sun exerted a stronger influence, and accordingly they introduced a solar year whose divisions they ascribed to Marduk. The stars were observed because their positions determined the seasons. Since the seasons govern organic life, a pernicious belief in the influence of the stars took root, a belief which prevailed for twenty centuries and which crippled the advance of science up to the time of Galileo. Diodorus Siculus, a contemporary of Julius Cæsar, describes this astrology in the following words, as given in a translation by Philemon Holland (1700):

"Therefore from a long observation of the Stars, and an exact Knowledge of the motions and influences of every one of them, wherein they excel all others, they (the Chaldean astrologers) foretell many things that are to come to pass.

"They say that the Five Stars which some call Planets, but they Interpreters, are most worthy of Consideration, both for their motions and their remarkable influences, especially that which the Grecians call Saturn. The brightest of them all, and which often portends many and great Events, they call Sol, the other Four they name Mars, Venus, Mercury, and Jupiter, with our own Country Astrologers. They give the name of Interpreters to these Stars, because these only by a peculiar Motion do portend things to come, and instead of Jupiters, do declare to Men beforehand the good-will of the gods; whereas the other Stars (not being of the number of the Planets) have a constant ordinary motion. Future Events (they say) are pointed at sometimes by their Rising, and sometimes by their Setting, and at other times by their Colour, as may be experienced by those that will diligently observe it; sometimes foreshewing Hurricanes, at other times Tempestuous Rains, and then again exceeding Droughts. By these, they say, are often portended the appearance of Comets, Eclipses of the Sun and Moon, Earthquakes and all other the various Changes and remarkable effects in the Air, boding good and bad, not only to Nations in general, but to Kings and Private Persons in particular. Under the course of these Planets, they say are Thirty Stars, which they call Counselling Gods, half of whom observe what is done under the Earth, and the other half take notice of the actions of Men upon the Earth, and what is transacted in the Heavens. Once every Ten Days space (they say) one of the highest Order of these Stars descends to them that are of the lowest, like a Messenger sent from above; and then again another ascends from those below to them above, and that this is their constant natural motion to continue forever. The chief of these Gods, they say, are Twelve in number, to each

of which they attribute a Month, and one Sign of the Twelve in the Zodiac. Through these Twelve Signs the Sun, Moon, and the other Five Planets run their course."

The Chaldean priests developed a most perfect astrology. They mapped out the positions of the stars for every day with such care that they could tell their true positions for some time in advance. The different stars either represented deities or were directly indentified with them. If, therefore, a Chaldean king wished to know which gods ruled over his destiny, he consulted the priests as to the position of the stars on his birthday and was informed of the chief events of his career.

This Chaldean belief that the celestial bodies were gods transformed astronomy into a religion. Hence astronomical theories were promulgated only by the ruling priest caste. To doubt the tenets of that caste was to expose oneself to merciless persecution, an Oriental trait that passed over to the nations of classic antiquity and to the semi-barbarous nations of the Middle Ages.

The Jews appropriated the Chaldean conception of the universe, but modified it, so that it was transformed from a polytheistic to a monotheistic conception.

No doubt the Chaldaic accounts of the beginning of the world influenced Egyptian thought. According to Maspero, the Egyptians believed that matter without form was shaped by a deity, always a different person in different parts of the land and by different methods, into the world as we see it.

The classic nations borrowed much of Egyptian civilization and with it Egyptian religion and science. For, the Greek creation myth, like all the others, assumes that chaos once existed and that out of it Gaa, the mother of all things, and her son, Uranos, the god of heaven, were created.

The Greek cosmogony was adopted by the Romans without noteworthy development. Hence it is that Ovid wrote on the origin of the universe much as Hesiod had done seven hundred years before. In that long interval of seven centuries the study of nature had advanced but little. Indeed it was not until the invention of the telescope that astronomy was lifted entirely out of the hands of the priesthood and placed upon a sure scientific footing. Before the invention of the telescope, therefore, astronomy appears merely in the garb of a myth. At its best it was metaphysical.

The rudiments of astronomical science are to be found in the efforts of the Chaldeans, Egyptians and Greeks to devise calendars and to mark time. That effort necessitated a study of the motions of the celestial bodies. Moreover, exigencies of husbandry rendered necessary some method of keeping track of the seasons so that seed time and harvest could be ascertained. The regular

occurrence of such events as the Nile flood made requisite suitable preparations. Hence the early Egyptians so built their temples that they might know the time of the summer solstice and hence the time when the flood might be expected. This was a matter of practical importance, not merely connected with religion or priest-craft, but on which the lives and the happiness of the people of Egypt depended, and might be compared with the modern time observations made at the great national observatories. The observation of the stars was carried on with at least this object in view, and gradually with the development of civilization time reckoning from the stars became an important consideration closely connected with the lives of the people. With the study of the stars for such a purpose naturally an amount of information as to their positions and motions was accumulated, and for centuries the practical side of astronomy was the study of the position of the stars and the motion of the planets. The astrology of the Chaldeans spreading westward increased rather than diminished the interest in the stars, for not only was the connection of the planets with natural phenomena and the mere reckoning of time studied, but the mystical element involving prophecy of future events attracted attention. In other words, astrology was a pseudo-science, for which reason it is difficult to estimate its benefits or to exaggerate its evils. In its scientific aspect it involved the observation and record of the position of the heavenly bodies with all the exactness that the mathematical and observational methods of the time could achieve. It enabled the motions of the planets to be studied as well as the positions of the fixed stars and the course of the sun as it passed through them. But, on the other hand, when the interpretation of the appearance of the skies was involved, superstition and poetic fancy had full sway, in which no doubt certain elements of self-interest and deception on the part of the priests or astrologers were not lacking. Hence these men did not study the sky to interpret phenomena on a scientific basis. Confined in the narrow limits of superstition, they not only made no progress but actually held back astronomy as they did other sciences.

That the work of the astrologer was mysterious there can be no doubt, and as no reason was assigned for the movement of the planets or the position of the stars, it was a natural assumption on the part of the people that some supernatural agency was at work, which also was connected with their lives and their future. With the beginning of the development of scientific astronomical theory proper the power and position of the astrologers began to wane—slowly, it is true, for when Tycho Brahe was invited to deliver lectures on astronomy at the University of Copenhagen, the first dealt very largely with astrology. Cardan and Kepler among the

distinguished astronomers of the Middle Ages, Roger Bacon, Burton and Sir Thomas Brown were among the men of mind who were interested, at least in part, in the teachings of the underlying basis of the cult. As explanations of the motions of the heavenly bodies on a rational basis were forthcoming, the doom of the astrologer, so far as participation in the scientific creed of the day was concerned, was sealed. If there was a natural explanation that could be accepted, how could supernatural influences condition the movements of the planets or the positions of the stars? If then these movements were natural and made in obedience to natural laws, how could they affect the future course of life and future occurrences that obviously had no connection with natural phenomena? The law of gravitation, which explained the solar system and the movement of the planets, corroborated this view and left only the comets as striking natural phenomena which could not be explained in a way that the popular mind could grasp. With the rise of learning and the growth of observation, the explanations of natural phenomena by astronomers secured acceptance by the people. Finally, when Halley's prediction of the return of his comet, first made in 1705, was verified in 1758, the reign of natural law in the world of the heavens became an accepted fact, from which only the ignorant or superstitious could dissent.

Distinctly different and apart from astrological influence was the work of Copernicus, whose researches marked the beginning of the new and philosophical science of astronomy, in which the element of mysticism was gradually displaced and observation and reasoning were depended on. Copernicus, as will be seen when the development of theories of the solar system is considered in an early chapter, returned to many of the fundamental ideas of Pythagoras and the early Greek philosophers, especially that the Sun was the center of the universe. He was a thoughtful student not only of Greek philosophy but of the work of such later astronomers as Ptolemy and his successors, so that when he announced a theory of the solar system in which the Earth and other planets revolved around the Sun as a center, it was based upon the fullest knowledge of previous reasoning and theory. Nevertheless he was casting to one side the tradition and the science of the day as it was then understood and presenting what was a conception of the heavenly world no less daring than original. His theory was a natural outcome of the revival of learning in the Renaissance, foreshadowed by the work of such men as Leonardo da Vinci and others, in whom the scientific spark had been awakened. With Copernicus the evolution of his heliocentric theory was a matter of scientific reasoning rather than of direct observation. But it marked the beginning of a series of epoch-making discoveries presented in a clear and positive form,

so that the theory of the revolution of the planets around the Sun became one of the fundamental canons of astronomy. Thus, as will appear in the course of our history, the Copernican theory in which the revolution of the planets around the Sun is made clear, Kepler's theory of planetary motion in which laws are stated to account for this motion, and finally, Newton's announcement of the great universal law of gravitation, are the foundation stones on which modern astronomical science firmly rests.

The invention of the telescope established the similarity in the bodies of the solar system and revealed facts that previously had been hidden from observers of the heavens. Indeed, with the invention of the telescope and the growth of mathematical science, there began an era of descriptional astronomy in which exact observation was combined with careful computation and mathematical analysis, an era which continued into the nineteenth century with undiminished vigor. Brilliant discoveries were made possible by improved and powerful instruments, accompanied by theoretical work of even greater value. In the middle of the nineteenth century new instruments were put at the command of the scientist which had a remarkable effect in extending the boundaries of the science. The telescope had facilitated merely the observation of the stars. The spectroscope, on the other hand, enabled the astronomer to ascertain their composition.

With the application of the spectroscope to astronomy began the welding of physics and chemistry with astronomy and the birth of that modern science of astrophysics, which has afforded data for the study of the serious problems connected with the evolution of the universe. From the soothsaying star-gazer of Chaldean times to the modern astrophysicist, who works in a laboratory as well as in an observatory, we have a development that is responsible for the aggregation of knowledge which we now possess of the vast universe with its suns, planets, stars and nebulæ.

The spectra of distant celestial bodies recorded on the photographic plate by the spectrographs of large telescopes are now studied in comparison with the spectra of terrestrial substances produced in the physical laboratory. Not only the nature and composition of the stars can be ascertained, but also their motion in space which are beyond the range of any telescope. The New Astronomy has become on its astrophysical side almost an experimental science with the methods and accuracy of the chemical or physical laboratory. It is from this modern astronomy, with its breadth and resourcefulness, that modern science looks not only for advances in its own particular field, but in the broader and ever interesting problems of cosmogony as concerned in the evolution of the stars and other bodies making up the universe.

CHAPTER II

THE EVOLUTION OF ASTRONOMICAL METHODS OF OBSERVATION

THE history of astronomical observation is the history of man's attempt to bring the stars near to him. His own senses are so feeble and so very subject to error that he has been constrained to devise subtle artificial senses which take the place of eyes and hands. Thus early he invented position-finders, which enabled him to determine with more or less precision a star's direction or position at a given time and not merely to guess at that position; great eyes, called telescopes, that see what his eyes can never see and also determine positions with greater accuracy; wonderful spectroscopes that analyze a star's composition as nicely as if it were a stone picked up in the road; and photographic devices that reveal secrets of star structure that otherwise would never be disclosed by his unaided senses.

For determining the position of the heavenly bodies the instruments used have always been comparatively simple. All are based on certain rudimentary geometric principles. As geometry was a science fairly well developed among the ancients, it is not difficult to realize that they had various means of measuring angles, both vertical and horizontal. In most ancient cases, however, the observers have failed to hand down their methods, merely recording the results without indicating the circumstances in which they were obtained, so that it is impossible to discuss the values of the observations and correct them in the light of recent discoveries. It is evident that the instruments of the ancients were simple, but their precise nature is altogether uncertain.

The earliest astronomical observations of which there is record were made by the Chinese. The Shu King, the oldest known scientific work, states that two thousand years before the present era the Chinese determined the seasons—that is to say, the positions of the Sun at the equinoxes and solstices—by means of four stars which have since been identified and found to be so suitable that a modern astronomer could not have made a better choice. The Chinese also determined, eleven hundred years before the present era, the obliquity of the ecliptic, which they found equal to 23 deg. 54 min. The obliquity, which varies, is now 23 deg. 37 min., and calculation shows that at the epoch of the Chinese observations it must have been 23

deg. 51 min. Hence the error of the Chinese determination was only three minutes of arc.

Among the few astronomical values which have remained constant during the history of man are the times of revolution of the planets. The Hindus determined the revolution of Mercury with an error of 4/10,000 of a day. For Venus the error was 23/10,000 of a day, for Mars 1/1,000 of a day. In the case of Jupiter the error amounts to one-quarter of a day, but it is to be remembered that the period of revolution of this planet exceeds 11 years, so that the same observer could not observe many returns of the planet to the same point of its orbit. This comment applies with still greater force to Saturn, the revolution of which occupies 29 years. Hence it is not astonishing that in this case the Hindus were six days in error.

Among the ancient Greeks is a measurement of a terrestrial meridian made about 200 B.C. by Eratosthenes (276 B.C. to 195 or 196 B.C.), who found the circumference of the Earth equal to 250,000 stadia by measuring the angular distance of the Sun from the zenith at the summer solstice both at Alexandria and at Syene in Upper Egypt by means of the length of shadow cast by a vertical pillar at noon at each place. According to the researches of Tannery, the stadium as an astronomical unit equals 157.5 meters (516.7 feet), which gives for the Earth's circumference a length of 39,690 kilometers (24,662 miles) instead of 40,000 kilometers (24,855 miles) as we know it. Here the precision is remarkable, especially when it is remembered that the measurement was effected by counting the paces contained in an arc of the meridian and by multiplying the number so found by the length of a pace.

The instruments most frequently employed by early astronomers were divided circles and compasses with simple sights which allowed the line of vision to be directed to the star under observation and its direction as compared with some other line of sight to be measured. Ptolemy's ring or astrolable, for example, described in the fifth book of his Almagest, and used to identify the relative positions of the stars and planets, was composed of two concentric vertical circles. The outer circle, about 16 inches in diameter, was fixed and graduated. It supported the interior ring, which was movable and carried the two sights. There was also a geometric square which was used in a manner analogous to that of a table of logarithms. Various forms of apparatus for the measurement of horizontal and vertical angles were early involved, and as the study of the heavenly bodies developed to a point where it was useful in navigation, the cross-staff or back-staff was invented, consisting of simple sighting bars with cross-pieces suitable for the calculation and measurement of such angles as the heights of the heavenly bodies above the horizon and their distance from one another. Quadrants of one form or another, with a sighting

bar and divided circular scale, and astrolabes, or celestial circles, also for the direct measurement of angles, were employed. Many of these, by the Middle Ages, were examples of accuracy of division.

A quadrant designed by Tycho Brahe (1546-1601), for example; was of 19 feet radius and had its circumference graduated to single minutes. Various forms of armillary spheres were constructed in which the stars were placed in their relative positions on great circles of the celestial sphere. Such devices served for much of the early astronomical work, taking the place of modern star charts.

Tycho Brahe, like his predecessors, employed wooden instruments. One of these was a large Ptolemy's ring, surmounted by a post carrying horizontal arms, by which it was turned in bearings like a capstan, so that the ring could be brought into any vertical plane. Tycho Brahe also constructed a mural circle, by means of which vertical angles could be measured. Hence it was by using the naked eye and rudimentary instruments that he accumulated observations of such precision that they served Kepler as the basis of the researches which led to the discovery of the laws of planetary movement.

The eye can distinguish an object whose diameter is equal to about 1/3,000 of its distance, which corresponds with an angular diameter of about one minute of arc. This was the measure of the precision of early observations. Its value may be appreciated by stating that it corresponds with the diameter of a lead-pencil seen at a distance of 70 feet. The telescope, by increasing the distance at which objects can be distinguished, therefore has been and is now the chief reliance of the astronomer in determining position. While the naked eye to-day may be said to have been very largely supplanted by spectroscopic and photographic observation, yet the telescope has constantly met the demands of astronomers as its power has increased and its scope widened.

By chance or otherwise it was found by a Dutch spectacle maker, Lippershey, about 1608, that two lenses when placed at some distance apart would act to magnify distant objects, just as a single lens would enlarge the image of a near-by object. This action of the lens can be explained by considering the effect on a prism of transparent material placed in the path of a beam of light. When a beam of light falls on one of the angular faces of the prism at a direction other than perpendicular to the face it is forced to change its direction on account of refraction, due to the change in medium. That is, a ray of light passing obliquely through air into a denser medium, such as glass, is bent toward the perpendicular, and in passing out from a denser to a rarer medium is bent away from the perpendicular. A lens may be considered as a collection of prisms of constantly changing angles, so that the effect would be to bend parallel rays coming from a point at infinite distance in such a way that they would all be brought to

a single point known as the focus. Consequently a telescope may be regarded as a light-gatherer.

The importance to astronomy of Lippershey's invention can be appreciated from the fact that as soon as Galileo heard of it he constructed such an instrument which, hardly the size of a small toy spyglass, magnified three times, or brought the heavenly bodies three times as near. He applied it to celestial observation in 1609.

The value of the telescope as an astronomical instrument became apparent immediately. It was from the use of his "optik tube," as he called it, that Galileo arrived at the conclusion that Ptolemy was wrong and Copernicus right—how will become apparent from a consideration of the discoveries made by Galileo. He did more than this, however; for by the application of the telescope to the observation of the stars he became in truth the founder of our modern science of astrophysics.

Galileo saw hosts of stars never before revealed to the unaided eye. The six stars in the Pleiades now appeared as 36, and various nebulous objects of light, such as the Milky Way, were found to consist of multitudes of fine stars clustered together. But his crowning achievement occurred on January 7, 1610, when in turning his telescope toward Jupiter he discovered four satellites of that planet and determined that their periods of revolution around Jupiter ranged from about forty-two hours to seventeen days. Here was a miniature system similar to that conceived by Copernicus. Was it any wonder that Galileo abandoned the Ptolemaic teaching? Thus Galileo was able to strike a serious blow at the infallibility of Aristotle and Ptolemy, by whom no mention had been made of the existence of such extra bodies. At this time, however, others besides Galileo were working with the telescope, among them Thomas Harriott (1560-1621) in England, Simon Marius (1570-1624) and Christopher Scheiner (1575-1650) in Germany. Thence forth observational astronomy with the telescope was anchored on a firm basis.

As was quite natural, telescopes eventually formed an important part of the equipment of the observatory of Tycho Brahe and of John Kepler (1571-1630). In one of Kepler's works on "Optics" is contained a suggestion for the use of a convex lens for an eye-piece in the construction of the telescope. Galileo's instrument consisted of a lead tube containing a large double-convex lens, which served as an objective, and a small double-concave lens at the eye-end in order to give an erect image—an arrangement which finds its counterpart in the modern opera glass.

Kepler's suggested improvement provided a more efficient and fairly modern astronomical telescope. The actual construction of an instrument of this type, however, is credited to Scheiner rather than Kepler, who was notably deficient in mechanical skill. After con-

siderable experimenting by various astronomers and instrument makers, it was found that a comparatively small object with a considerable focal length was most useful and effective. In 1672 Capani, of Bologna, constructed an instrument of this kind 136 feet long, while Auzout actually made a telescope 600 feet in length, which, however, failed to work. These, of course, were skeleton structures not mounted in tubes. Perhaps the best of them were those of Huygens (1629-1695), whose skill in grinding lenses stood him in such good stead that he was able to construct a telescope with which he determined the ring of Saturn. Huygens' telescope had considerable focal length. He placed the object glass on a tall vertical pole or staff so balanced that it could be moved in any direction by means of a cord. The observer on the surface of the Earth was supplied with an eye-piece which he maintained in a straight line with the star he was observing by means of a cord.

All these telescopes were "refractors." They were subject to certain inherent defects, chief among which was the difficulty of bringing to a single focus all the rays of different colors. The seventeenth-century philosophers believed it impossible to overcome the unequal refrangibility of the different colored rays of light which produced "chromatic aberration" and resulted in an image indistinct for the blurring of various colors. Accordingly they gave up the idea of perfecting the refracting telescope and directed their attention to constructing an instrument on a different principle, using a concave mirror to form the image of the object observed. Mersenne, in 1639, suggested the employment of a spherical mirror, but the idea appears to have been dropped. Quite independently, James Gregory, in 1663, proposed a similar arrangement, using, however, a parabolic in place of a spherical mirror. At that time he could not find a workman able to construct such a mirror. In the Gregorian instruments the parabolic reflector is placed at the lower end of the tube, while on its axis and a short distance beyond its focus is placed a small concave reflector. The light from the distant object falls upon the large mirror, from which it is reflected back to the small one, which throws it back through a hole in the center of the large reflector. It then passes into the eye-piece, which, indeed, in Gregory's time had been much improved by Huygens.

Gregory's efforts turned Newton's attention to reflecting telescopes. In 1669 he cast his first disk and began to grind it, but it was not until 1672 that he had real success. Then he made two small instruments, one of which was only about an inch in diameter, with a magnifying power of about 38. The principle of Newton's telescope differed from that of Gregory's in that it had a small plane mirror placed in the cone of light from the reflector at an angle of 45 degrees. Being placed inside the focus, this mirror brought the light cone at right

angles to its original direction, thus forming the image outside the tube and obviating the necessity of a hole in the parabolic reflector.

About the same time that Newton completed his instrument the Cassegrain construction was proposed, which was similar in construction to the Gregorian telescope, except for the small mirror. In the Gregorian this mirror was concave. Cassegrain (1672) proposed the use of a concave mirror inside the focus. It brought the light from the object to a focus through a hole in the center of the large parabolic mirror.

Owing to the difficulty in obtaining a suitable mirror alloy, little progress was made for some time in constructing reflecting telescopes. In 1718, however, Hadley, the inventor of the sextant, constructed one on the Newtonian principle, 5 feet in length. The instrument magnified over 200 times and revealed as much as the old refracting telescopes. Perfect as this Newtonian telescope seemed to be, the Gregorian type held the field until 1774.

By using a small Gregorian telescope Herschel had his attention directed to the wonders of astronomy. His income being too limited to purchase an instrument, he set about making one for himself. During his life he is said to have made upward of 400 telescopes, mostly of the Newtonian type. Among his earliest efforts was the construction of a 5-foot reflector, which was a wonderful success. Then came one 7 feet in length. The largest of his instruments was completed under George III. in 1789. This telescope surpassed all his previous efforts, for it was actually 40 feet long and had a reflecting mirror 4 feet in diameter. The story of Herschel's work with this great telescope would fill a volume.

The largest telescope of the reflecting type was constructed by Lord Rosse, an Irish peer, and used at Parsonstown. It had mirror of 54 feet focus and a diameter of 6 feet, but it could be used only for observations on or near the meridian. While out of use for many years, it long held the record for size, which, however, is now taken by the 100-inch reflector recently completed for the Mount Wilson Solar Observatory, California.

The case of the refracting telescope, which as we have seen had been all but abandoned on account of its chromatic aberration by the seventeenth-century astronomers and physicists, was not as hopeless as they believed. Notwithstanding Newton's dictum that it was useless to try to improve it, owing to the impossibility of producing refraction without dispersion, Euler read a paper before the Berlin Academy in 1747 proving mathematically the possibility of correcting both the spherical and chromatic aberration of an object glass. Upon reading Klingenstierna's paper corroborating Euler's views, John Dollond made a series of most valuable experiments which led him to the solution of the problem of the achromatic object glass—namely, that

oy properly combining two kinds of glass, flint and crown, he could unite the colored rays fairly well and still have refraction to unite the incident rays to form an image.

Dollond's discovery occurred in 1758; his work soon became famous. He was surely master of his subject and had a clear field for many years. Like other opticians, he labored under great difficulties in securing glass suitable for telescopes of any diameter. Fortunately a genius had taken hold of this problem in the person of Guinand, a Swiss watchmaker, who after long experimenting, solved the problem of making fine disks of optical glass. He associated himself with the celebrated Fraunhofer in 1805, and they successfully made optical disks up to fifteen inches aperture. To Fraunhofer are due many of the most important discoveries in the theory of the achromatic objective.

With proper optical glass and methods of correction the refracting telescope soon came into its own. The size of the objectives was increased so that sufficient amounts of light were gathered to form a distinct image. The best makers of Europe gradually developed both lenses and mountings so that precision of measurement and ease of adjustment were secured. It was in the United States that the best work in this field began to be carried on. The lenses of Alvan Clark gained an international reputation. An objective 30 inches in diameter was made by him for the Russian Observatory at Pulkova soon after a 26-inch telescope had been completed for the U.S. Naval Observatory in Washington. These were succeeded by the 36-inch instrument of the Lick Observatory and the 40-inch telescope of the Yerkes Observatory, with both of which results in proportion to their increased size have been obtained.

The seventeenth century really marks the beginning of instrumental work and accurate measurements in astronomy. The vernier, which made it possible to subdivide linear and circular scales with accuracy, made its appearance in 1631. In 1640 the optical axis or line of direction of the telescope was practically defined, and the micrometer was invented by William Gascoigne (1612-1644), which was the forerunner of the filar micrometer, so essential to modern astronomy, where an image at the focus of a telescope can be measured.

The micrometer is indeed an important adjunct to the telescope, for, unless angular distances can be measured, the mere bringing nearer of the celestial bodies would have but a limited amount of usefulness. In the micrometer of William Gascoigne two pointers carried by a single screw were placed at the focus of a telescope. When these pointers were parallel they pointed to zero; but, by revolving the screw, they could be separated and the number of revolutions or parts of a revolution could be read from a divided head. Consequently all that it was necessary to know was the distance

between two successive threads of the screw in order to obtain an exact value for any distance which the pointers might separate. Now if it were desirable to determine the angular distance between two stars, each pointer was set on a star and the distance between them was thus gradually measured, so that by simple mathematics the corresponding angular distance could be computed.

Micrometers soon became an important part of exact observation with a telescope. Auzout and Picard made subsequent improvements, so that finally a micrometer resulted in which a spider filament was placed on a frame moved by a screw with graduated head, thus enabling increased precision of observation to be obtained. This is the fundamental device now used with various improvements and refinements. Roemer, who was the first to determine the velocity of light, improved the micrometer in 1672 by adding springs to take up the lost motion. He also constructed the first meridian telescope in 1689. By the middle of the seventeenth century the use of telescopic sights for determining the position of the stars had become established. The precision of the observations of that epoch may be estimated at 10 seconds of arc, which corresponds to the diameter of a lead pencil seen at a distance of about 550 feet.

Methods and instruments continued to improve. The observations of Lalande attained a limit of precision of one second of arc, corresponding to a pencil at 5,500 feet. At the beginning of the nineteenth century great improvements were made. In 1875 the limit of precision had been reduced to one-half a second, which removes the lead pencil to 11,000 feet or more than 2 miles.

For minute measurements one of the most useful devices has been the heliometer or divided object glass micrometer, the first really available type of which was constructed by Fraunhofer for the observatory at Königsberg. In this instrument an object glass or lens is used which is divided along its diameter. The two parts of the glass are mounted so that they can be moved laterally with respect to each other. Consequently each half supplies a distinct image of the same object, but separated by a strictly measurable amount. Thus, if a double star is under examination, the two half lenses into which the object glass is divided can be moved until the upper star in one image is brought into coincidence with the other star in the lower image, so that the distance apart becomes known by the amount of motion employed. By using screws with heads of considerable size to move the halves of the object glass, the heliometer can be read to the thousandth part of a revolution, and in the case of the Königsberg instrument such a division, equivalent to 1/20 of a second of arc, could be measured with accuracy. This new instrument, which was not mounted until 1829, three years after the death of Fraunhofer, was at once employed by Bessel to solve the problem of

star distances. His measurement of the parallax of the star known as "61 Cygni," corresponding with a distance about 400,000 times that of the Earth from the Sun, not only was considered ascertained beyond question, but is spoken of by Miss Clerke, as "memorable as the first published instance of the fathom line so industriously thrown into celestial space having really and undubitably touched bottom." In 1874 the heliometer was applied to the observation of the transit of Venus, and again, in 1877, when Mars came into opposition with the Sun, Sir David Gill, using the heliometer, made a valuable determination of the solar parallax, obtaining a value of 8.78 seconds, corresponding with a distance of 93,080,000 miles. By this time the heliometer had become an accepted method for improving astronomers' knowledge of the Sun's distance. A number of heliometers were employed in coöperation at different points of the Earth's surface, the work of Professor Elkins at Yale in connection with Sir David Gill at the Cape of Good Hope Observatory being especially notable.

Another modern development of the telescopic astronomy has been the direct measurement of the magnitude and brightness of a star, thus superseding to a great degree the judgment of the eye upon which the older astronomers had depended from the days of Hipparchus. The photometers (light measurers) used with telescopes for this purpose consist either of those designed to cut down the amount of light furnished by a measurable amount and thus cause the star to disappear, or those in which conditions are so arranged that the light of the star appears just equal to some standard light. Under the first head is the so-called "cat's eye," in which a wedge of dark neutral tinted glass is placed close to the eye, either at the eyeball of the eyepiece or at the principal focus where the micrometer wires are usually placed. As the wedge is introduced until the star just disappears the graduation is read, which graduation can be reduced to a scale of magnitudes. In the other class of photometers the light of the star is compared with an arbitrary artificial star formed by light from an oil lamp shining through a small aperture.

To Huygens is due the application in 1655 of the pendulum to the practical measurement of time, thus giving us a clock so regulated that it was possible to make accurate time observations. The invention of the pendulum clock, patented in 1657, therefore marks a distinct epoch in astronomy.

The most usual and most useful form of mounting for a telescope is the equatorial, the principal axis of which is inclined at an angle equal to the latitude of the observatory and is directed toward the North Pole in the Northern Hemisphere and toward the South Pole in the Southern Hemisphere. The axis of the instrument is thus parallel to the Earth's axis of rotation and is therefore called the

polar axis. It carries a graduated circle which is parallel to the celestial equator, known as the hour circle, from which circle may be read the hour angle of the body upon which the telescope happens to be pointed. The polar axis also carries the bearings of the declination axis, which is perpendicular to the polar axis and carries the telescope itself and the declination circle. When the equatorial telescope is directed toward a star or a planet it is necessary only to use clock-work machinery to cause the polar axis of the instrument to turn with a uniform motion in order to follow any star or planet which otherwise would soon be carried out of the field of view by the rotation of the Earth. The equatorial also enables the observer to look at once to a particular part of the heavens where a given body is expected to be at a given time.

The mounting for a modern equatorial telescope requires large and heavy moving parts. Where a solar or stellar image is desired it does not seem desirable to employ such a heavy mechanism. To Léon Foucault, about 1868, the idea occurred to construct a fixed telescope with a mirror, moving with one-half the angular velocity of the Sun, deflecting a beam in a fixed direction. Such an instrument was constructed and was employed with good results, altho its operation was marred by imperfections in its driving mechanism. However, the device did not attract much attention until plans were made in the eclipse expedition of 1890 for extensive photographs of the phenomenon. It was proposed to use the instrument in connection with a second mirror to produce an image which would not move. This device, now called a "cœlostat," was found admirable for eclipse photography. Experiments were made at the Yerkes Observatory to construct such an instrument for solar work. The work was subsequently transferred to the Carnegie Institution Observatory on Mount Wilson. An extension of the same principle may be found in the tower telescope of that institution, where a cœlostat is mounted on the top of a skeleton tower and a beam of light is reflected to a laboratory beneath. To-day the most modern and efficient reflecting telescope of large size is the 100-inch instrument designed for the same observatory by Prof. G. W. Ritchey.

At the present time both refracting and reflecting telescopes are in use and have been brought to a great degree of perfection. Just which is the better it would be hard to say. The old speculum metal reflector has been almost discarded and glass, coated with silver, has been substituted. The glass is much superior to the metal, as it can be figured more accurately, and if tarnished the silver can be removed without changing the figure of the mirror.

Again, much study has been given in France to a form of telescope known as the equatorial coudé, in which the optical axis of the telescope is parallel to the axis of the Earth and the light of the star

is reflected into it by two mirrors. Such an instrument, constructed for the Paris Observatory, has been very convenient for the astronomer, who can sit in his chair and observe the stars as easily as he can use his microscope. But the loss of light and definition by the double reflection, as well as the deflection of the mirrors and the varying temperatures to which the different parts of the instrument are subjected, render this construction far from perfect.

CHAPTER III

PHYSICS OF THE HEAVENLY BODIES

To GAIN a knowledge of the composition and nature of the celestial bodies is the fundamental problem of astronomy. Unable to bring a celestial body or a specimen from it, except in the rare case of a meteorite, to the chemical laboratory for study, the astronomer is dependent entirely on a study of the energy that it emits in the form of light and heat rays. Strange as it may seem, these rays furnish as true a record of their birth and life history as if a sample from the distant star had been tested in the assay furnace or with the reagents of the chemist. The simple instrument called a spectroscope gives an accurate and permanent record which affords complete data for the studies of the astronomer. Modern spectroscopes have refined observation to a point where the distant stars are compelled to yield up their secrets.

White light is composed of various forms of vibration which, taken by themselves, will supply light of various colors from red to violet. It was found by Sir Isaac Newton in passing a beam of white light through a prism that not all of the rays are bent equally toward and away from the perpendicular, but that the amount of bending depended upon their color, or as it is now termed, their wave length and position in the solar spectrum. Thus, when he permitted a beam of white light, emerging from a hole in a shutter, to fall upon a prism in a dark room, he found that there was produced after its emergence a brightly colored band with the red at one end, where the waves were refracted the least, and shading through yellow and green to violet, where the waves were bent or refracted most. Consequently, if there were a source of light capable of furnishing one color and that only, it would be obvious, wherever that color appears in the bright band produced by the prism, that it radiated from a particular source.

Before 1753 a young Scotchman, Thomas Melvill, noticed that when various compounds of sodium were introduced into an alcohol flame and viewed through a prism there appeared a particular shade of yellow light, which was always bent or refracted to a fixed and definite degree. Others repeated these experiments, and finally Fraunhofer (1787-1826), a great optician of Munich, rediscovered this

deep yellow ray and found its place in the spectrum. The same phenomenon was noticed by many other experimenters. Indeed, the omnipresence of the yellow light was often an embarrassment in spectral research. That this yellow line was due to sodium was pointed out by William Swan. Finally, it was noted that the distribution of sodium was so general and the prism test of its presence so delicate that its absolute exclusion was well nigh impossible.

Before Fraunhofer's experiments, the round hole in the shutter of Newton had been supplanted by a slit or crevice about one-twentieth of an inch wide, and the spectral band thus formed from sunlight was not only continuous but free from overlapping images, so that the colors were shown in their purity, crossed by seven dark lines. In the course of his experiments Fraunhofer not only used the slit, but added to it the telescope of the modern spectroscope. He was surprised to find not merely seven but thousands of dark transverse lines, many of which he mapped, counted and designated by the letters of the alphabet.

Not only did he examine sunlight in this way, but also the light of the Moon and planets, and found that stellar spectra, too, were crossed by the same dark lines. In the case of certain stars there were even dark bands. He found that one or rather a pair of solar lines which he had marked in his map with the letter "D" coincided exactly with the yellow beam which accompanied incandescent sodium vapor. The coincidence was noted by Fraunhofer, but the explanation came in 1859 from the distinguished German physicist, Professor Gustav Robert Kirchoff (1824-1887). He it was who sent a beam of bright sunshine through sodium vapor and discovered that the "D" line of Fraunhofer, instead of being effaced by the flame, was strengthened. The same held true with iron. The inference was of course drawn that sodium and iron were constituents of the glowing atmosphere of the Sun and that light of the particular wave length in passing through such an atmosphere was absorbed.

This principle has been formulated by Miss Clerke as follows: "Substances of every kind are opaque to the precise rays which they emit at the same temperature—that is to say, they stop the kinds of light or heat which they are then actually in a condition to radiate. But it does not follow that cool bodies absorb the rays which they would give out if sufficiently heated. Hydrogen at ordinary temperature, for instance, is almost perfectly transparent, but if raised to the glowing point—as by the passage of electricity—it then becomes capable of arresting, and at the same time of displaying in its own spectra, light of four distinct colors." In these few words we have the essence of spectroscopic chemistry and astrophysics. Materials of the Earth when heated to incandescence give a bright line spectrum characteristic of the individual element,

but the same materials in the Sun show a spectrum marked by dark lines.

While spectrum analysis was applied to chemistry and terrestrial materials by Bunsen, Kirchoff worked industriously and made a map of the solar spectrum some eight feet in length, in which the various lines of the elementary bodies were represented. The spectroscope, as constructed by Kirchoff, consisted of a slit placed at the principal focus of the convex lens to make the rays parallel for their passage through the prism. In order to secure greater dispersion, several prisms were added and the emerging beam was passed through the telescope to form an image of the spectrum. The new instrument at once presented an enormous number of lines for study, not only of the Sun, but of various other celestial bodies. It was soon applied to the observing end of an astronomical telescope, so that the celestial image was formed directly at the slit of the spectroscope.

By increasing the number of prisms the dispersion of the spectroscope can be increased, and a longer spectral band produced, in which otherwise closely adjacent lines are increasingly separated. But in passing through a number of prisms there is considerable loss of light by reflection and absorption, so that a limit is soon set to the number of prisms employed. Another form of spectroscope which makes use of a grating or a number of fine lines ruled very closely together on a transparent or a reflecting surface, has been found to possess greater dissolving power without any accompanying loss of light. In fact, the resolving power of a perfect grating depends simply upon the total number of lines it contains, so that the light efficiency per unit area may be as great for a large grating as for a small one.

The principle of the grating depends upon the interference of the various minute light waves caused by a series of lines, amounting to from ten to twenty thousand to the inch, ruled on a transparent or a reflecting surface. The mathematical discussion of the formation of the spectra by the interference of the light waves in passing through or being reflected from such a grating can hardly find a place here. The result, however, is essentially the same as in the case of the prism. As soon as the dispersion of light was obtained by this means it was found that it could be studied quantitatively, and that the grating could be used for astronomical measurements with as great facility as the prism spectroscope.

Lewis M. Rutherfurd of New York was able to make excellent gratings about 1864, but it remained for Professor Henry A. Rowland (1848-1901) at the Johns Hopkins University to construct a dividing engine with a screw, practically free from error, which would move a small plate of polished speculum metal by regular in-

tervals of 1/15,000 of an inch under a diamond point which traced sharp and regular lines. This machine not only was remarkably sensitive in its action, but automatically compensated for any minute irregularities in the screw. It was made to work at a constant temperature. It automatically proceeded with its ruling night and day until a grating of the desired length was completed. Professor Rowland for the first time ruled gratings on concave surfaces and used them in place of the prism of the ordinary spectroscope. The spectra obtained with these diffraction gratings in conjunction with special lenses were many feet in length and could be photographed in sections on photographic plates, each of about 20 inches in length.

The grating spectroscope has been modified by Professor A. A. Michelson of the University of Chicago, who has devised a new form of grating in which a series of glass plates precisely equal in thickness are placed one on another like a flight of steps. A parallel beam of light when transmitted through them is resolved into spectra of a very high order, exceeding even those of Rowland's largest gratings, so that compound lines in the spectrum can be studied with facility.

The application of the spectroscope has made of astronomy an experimental science, with methods and instruments for research and future progress fully as promising as may be found in any of the physical or natural sciences. The spectroscope has not only amplified astronomy, but it has developed the new science of astrophysics, in which astronomy is combined with physics. New methods and instruments for research already have brought to light striking discoveries which have compelled the modification of older astronomical and cosmical theories.

In connection with the spectroscope it is possible to measure the temperature of the radiations sent out from the Sun and the stars with a high degree of accuracy by means of the bolometer, a sensitive thermometer, invented by Professor S. P. Langley. It consists of two very fine threads of platinum wire about 1/2,500 of an inch in thickness, mounted side by side within a constant temperature chamber. On one of these wires the radiation is permitted to fall, while the other is carefully shielded. Any change in the temperature of the wire on which the light or heat waves fall produces a difference in its electrical resistance that can be measured with a high degree of precision, so that a difference of less than one-millionth of a degree in the temperature can be clearly indicated.

The spectrum formed by the spectroscope is caused to move slowly across the exposed platinum wire of the bolometer and a galvanometer in the circuit reflects from its mirror a spot of light upon a photographic plate, so that the deflections of the magnetic needle are photo-

graphed and registered, thus indicating the intensity and energy at the different parts of the spectrum. This instrument was first used by Langley to determine the amount of heat received from the Sun on the top of Mount Whitney in 1881, and since that time it has been employed by him and his successors at the Astrophysical Laboratory at Washington and also at Mount Wilson. The problem that the bolometer seems capable of solving is to determine the atmospheric absorption of light and heat in the passage of the Sun's rays to the Earth. It has also been used to measure the heat spectrum of the Moon and some of the brighter stars; in the case of the former showing that the Moon is very cold, as there is a considerable quantity of heat radiated having a wave length greater than that of the heat radiated from a block of ice.

After the fundamental work of Kirchoff in identifying the spectral lines of the Sun and the stars with various terrestrial materials it was but natural that the composition of stars as shown in their spectra should be thoroly attacked by astronomers. Among the first of these was Sir William Huggins, who devoted the greater part of a useful scientific life to research of the heavenly bodies, especially as revealed by the spectroscope.

In 1862 Huggins, Secchi and Lewis M. Rutherfurd began their researches in stellar spectra that enabled them to classify and compare the spectral bands furnished by the different stars. It was the spectroscope in the hands of Sir William Huggins that made possible the solution of the riddle of the nebulæ, the nature of which for long years had been a vital point of discussion among astronomers. On August 29, 1864, directing his spectroscope to the planetary nebulæ in Draco, Huggins saw, instead of the bright band he anticipated, a single line which subsequently was resolved into three lines. Thus he proved that the nebula was not an aggregation of stars or incandescent solid materials, which would have afforded a continuous spectrum crossed by dark bands and a luminous gas.

The effect of the spectroscope on astronomical research is thus summarized by Professor Hale: "In astronomy the introduction of physical methods has revolutionized the observatory, transforming it from a simple observing station into a laboratory. The interest of the student of astrophysics is no longer confined simply to celestial phenomena. For astrophysics has become, in its most modern aspect, almost an experimental science, in which some of the fundamental problems of physics and chemistry may find their solution. The stars may be regarded as enormous crucibles, in some of which terrestrial elements are subjected to temperatures and pressures far transcending those obtainable by artificial means. In the Sun, which appears to us not merely as a point of light like the stars, but as a vast globe

whose every detail can be studied in its relationship to the general problem of the solar constitution, the immense scale of the phenomena always open to observation, the rapidity of the changes and the enormous masses of material involved provide the means for researches which could never be undertaken in terrestrial laboratories. Hence it is that astrophysics may equally well be regarded as a branch of physics or as a branch of astronomy."

The great advantage of the spectroscope over the eye or the direct image from the photographic plate is its ability to analyze the action of light. While the intensity of light suffers in its journey through space, yet the nature or character of the light undergoes practically no change, so that the light from a distant star, separated from the Earth by an interval that seems to us almost infinite, can be received in our spectroscope and be resolved into a spectral band with difficulty but slightly greater than that which would be found in the employment of a luminous source of light at the opposite end of the laboratory table.

The spectroscope, therefore, can be used in astronomy to determine the composition of a distant body according to the principles of spectrum analysis. But this is not all. It also enables the determination whether the light from a luminous body in the heavens is approaching or receding, and whether the light emitted from such a body is the same to-day as it was yesterday or a half century ago, and whether it comes from one or more bodies which the eye and perhaps the telescope cannot separate, but which are distinctly separate. Hence the astronomer is only too glad to remove the eyepiece from his telescope and put in its place some spectroscopic device which will analyze the light into separate colors and give him much valuable information as to the constitution and motions of even the most distant star.

The value of the spectroscope is greatly increased by the application of photography. The general nature of a spectroscopic investigation can best be indicated by abstracting from Professor Hale his description of solar spectrum analysis: "Sunlight must be reflected from a mirror to a heliostat (driven by clockwork, to maintain the beam in a fixed direction) to the slit. Between the slit and the heliostat a lens is introduced, for the purpose of forming an image of the Sun upon the slit. When the illumination is secured in this way, the whole grating is filled with light from the diverging rays. The grating then produces an image of the solar spectrum upon the photographic plate, where it may be recorded by giving a suitable exposure.

"To facilitate an accurate comparison, the solar spectrum is photographed side by side on the same plate with the spectrum of the substance whose presence in the Sun is to be determined. In order to

accomplish this, one-half of the slit is covered, and the sunlight is admitted through the other half. Thus the solar spectrum is photographed on one side of the plate. After this exposure is completed, the sunlight is shut off, and the screen in front of the slit moved so as to cover the half previously open and to uncover the other half. The image of the Sun on the slit of the spectroscope is then replaced by an image of an electric arc light, burning between two poles of iron. The spectrum of the iron vapor is thus produced on the plate, and a strip of this spectrum is photographed beside the strip of solar spectrum.

"The bright lines of iron are represented in the solar spectrum by corresponding dark lines which accurately image them in position. In Rowland's work on the solar spectra thousands of lines were found to correspond with the iron lines given by the electric arc.

"The same process can be employed to determine the presence of other substances in the Sun. In the case of metals, the electric discharge may be caused to pass between two metallic rods, or fragments of the metal may be placed in a hole drilled in one of the carbons of an ordinary electric arc-lamp. In the latter case the spectrum of carbon, and also of impurities which the carbon poles always contain, will appear on the plate with the spectrum of the metal in question. But these extra lines may always be identified, and usually give no trouble. The identification of the solar lines, however, is not always so simple as in the case of iron. Many substances are doubtfully represented in the Sun by only a small number of lines, and it is sometimes very difficult to decide whether a few apparent coincidences are sufficient to warrant one in drawing definite conclusions. The matter is usually determined by ascertaining whether certain well-known groups of lines, which for various reasons are considered to be especially characteristic of an element, are actually represented. If these groups are absent, an apparent coincidence with certain less characteristic lines belonging to the same element should be regarded with suspicion. In the case of gases, the comparison is effected by the aid of vacuum tubes, in which the gas, usually at low pressure, is illuminated by an electric discharge. Thus the lines given by a hydrogen tube in the laboratory have been shown to coincide in position with lines ascribed to hydrogen in the Sun.

"After many years of study of the solar spectrum by these methods Rowland reached the conclusion that the chemical composition of the Sun closely resembles that of the Earth. Certain elements, such as gold and radium, iodine, sulphur and phosphorus, chlorine and nitrogen, have not been detected in the Sun. But this does not prove that they are certainly absent, as their level in the solar atmosphere, or the low degree of their absorptive effects, might prevent them from

being represented. On the other hand, various substances not yet found on the Earth are shown by many unidentified lines of the solar spectrum to be present in the Sun. Some if not all of these will probably be discovered by chemists, just as helium was found by Ramsay in clevite. Rowland remarked that if the Earth were heated to a sufficiently high temperature it would give a spectrum closely resembling that of the Sun."

CHAPTER IV

THE EVOLUTION OF ASTRONOMICAL INSTRUMENTS AND METHODS—CELESTIAL PHOTOGRAPHY

After the spectroscope, photography has been the most useful tool of the astronomer, and to its aid must be credited some of the most important work of the latter half of the nineteenth century. For the development of celestial photography as outlined in the present chapter an interesting paper by Professor E. E. Barnard supplies in large part the material. According to Professor Barnard, the application of photography to astronomy may be said to date from the very first announcement of Daguerre's wonderful discovery of the production of a permament image by the effect of light upon silver salts. "The celebrated French astronomer, Arago, quickly foresaw its great possibilities, especially in the faithful delineation of the surface features of the Sun and the Moon, for these two objects at least were bright enough to register themselves with the sluggish materials then in use." It was of course obvious to astronomers and physicists that the formation of an image on a sensitized plate was in no way different from that produced at its focus by the telescope lens and that the image of a celestial body could be produced as well as any other.

It was from America that the first practical work came, and "within less than one year from the announcement of Daguerre's discovery, in March, 1840, Dr. John W. Draper of New York city succeeded in getting pictures of the Moon which, though not very good, foreshadowed the possibilities of lunar photography. Five years later, at the Harvard College Observatory, Bond, with the aid of Messrs. Whipple and Black, of Boston, succeeded in obtaining still better pictures of the Moon with the 15-inch refractor. These pictures on daguerreotype plates aroused great interest, especially in England. However, the difficulties encountered led to failures generally, except in the case of De la Rue, Dancer and one or two others. In 1858 De la Rue, using a 13-inch metal speculum reflecting telescope, without clockwork, and guiding it by following a lunar crater seen through a plate, made the most important of the early efforts at lunar photography." His photographs were the best until those made in America,

in 1860, by Dr. Henry Draper, son of the illustrious John W. Draper. He secured excellent photographs of the Moon, superior to any previously made, and capable of considerable enlargement. These pictures were the best taken until Lewis M. Rutherfurd began his remarkable work about 1865. His admirable photographs of the Moon were made with a refractor of 11-inch aperture, which, constructed under his immediate supervision, was the first telescope corrected especially for the photographic rays.

"The completion of the Lick Observatory in 1888 marked another decided advance in astronomical photography, especially of the Moon. The great focal length of this magnificent instrument gave an unenlarged image of the Moon about six inches in diameter, which in itself was a great advantage." Good results were also secured with the Yerkes refractor.

Admirable lunar photographs have been made by MM. Loewy and Puiseux, with the equatorial coudé, at Paris, and have shown the usefulness of this singular instrument for such work.

"The first picture of the Sun seems to have been made on a daguerreotype plate by Fizeau and Foucault in 1845," says Professor Barnard. "During the total eclipse of the Sun on July 28, 1851, a daguerreotype was secured with the Königsberg heliometer (2.4 inches in diameter and 2 feet focus) by Dr. Busch, which appears to have been the first photographic representation of the corona. It showed considerable detail quite close to the Moon."

But in the early eclipses photographic work seems to have been devoted mainly to representations of the solar prominences, which at that time were as rarely seen as the corona itself. "During the eclipse of 1869, however, Professor Himes secured a photograph which showed the brighter structure of the corona. Similar pictures were also obtained during the same eclipse by Mr. Whipple, of Boston. The corona was also slightly shown on pictures made as early as 1860 by M. Serrat. None of them, however, showed more than slight traces of the corona, extending only for a few minutes of arc from the Moon's limb. Nearly all the pictures seem to have been taken with an enlarging lens, which was doubtless used to get the prominences on a larger scale.

"The first really successful photographs of the corona were obtained at the eclipse of December 22, 1870, when it was shown on the plate to a distance of about half a degree from the Moon's limb. This picture, made by Mr. Brothers, at Syracuse, Sicily, showed a considerable amount of rich detail in the coronal structure; the same can also be said of the photographs of this eclipse taken by Colonel Tennant and Lord Lindsay's party. These seem to have been the first pictures that really showed the great value of photography for

coronal delineation. The eclipse of 1871 was still more successfully photographed, and an excellent representation of the corona, full of beautiful detail, was secured.

"In 1878 extensive preparations were made to observe the eclipse of July 29 of that year. Photography was to play an important part, though astronomers did not rely very strongly upon it; for it appears that all were prepared to make the customary drawings of the corona. Unfortunately each person faithfully carried out that purpose. A most suggestive illustration of the uncertainty of such work is found in the large collection of drawings published in a volume issued by the United States Government relating to the eclipse of 1878. An examination of these forty or fifty pictures shows that scarcely any of them would be supposed to represent the same object, and none of them at all closely resembled the photographs. The method of free-hand drawing of the corona made under the attending conditions of a total eclipse received its death blow at that time, for it showed the utter inability of the average astronomer to sketch or draw what he really saw under such circumstances."

In the eclipses of 1882, 1886 and 1889 photography played a part of increasing importance in the observations. In the latter year there were a large number of amateur photographers who took advantage of the eclipse to make many photographs, which in a number of cases, were taken in a systematic and scientific manner. At the Lick Observatory a beginning was made in eclipse photography with an extemporized apparatus and successful exposures were made. During the eclipse of 1896 important work was done in photographing the flash spectrum or the momentary reversal of the Frauenhofer lines which occurs when the edge of the Sun disappears behind the Moon or reappears from it and for an instant exposes the reversing layer, which was first seen by Professor Young at the eclipse of 1870. This photograph was made by a young Englishman, William Shackleton, who, on exposing a plate at the critical instant of the reversal of the lines, caught for the first time the fugitive bright lines which are visible for only about a minute. This gave a permanent visible record of the phenomenon which removes it from the class of hasty visual observations. Twentieth century eclipse photography has become thoroughly systematized.

The photographing of such a minute point of light as a star is quite different from that of a luminous or brilliant body like the Sun or Moon. Yet it was early essayed, and from the first photograph of a star by Bond in 1850 to the present time stellar photography has gradually risen to a prominence as remarkable as it is important. Indeed, it is now quite indispensable. The principal reason for the real increase of importance in this work, however, was the success-

ful introduction of the very rapid dry plate. The wet or collodion process, which astronomers soon pushed to its limits, was poorly adapted to the photography of the stars, and of no use whatever for comets and nebulæ. "Notwithstanding the inherent difficulties of the wet plate, the photographs of the star clusters, etc., of the southern skies, obtained under the direction of Gould with an 11-inch photographic refractor by the wet process, were of the highest value and showed upon measurement a striking agreement in accuracy with visual work. The same can be said of Rutherfurd's photographs of the Pleiades, Praesepe, etc., which were made prior to Dr. Gould's, and which were the first photographs of the kind.

"As early as 1857 Bond had shown, by measurement of a series of photographs of the double star Mizar, that the highest confidence could be placed in measures of star plates. This was subsequently fully verified by Gill, Elkin and others. As regards absolute accuracy Dr. Elkin showed in 1889 that measures of a photograph of the Pleiades taken by Mr. Burnham, with the great telescope at Mount Hamilton, had equal value with the heliometer measures of the same stars."

By 1881 or 1882, however, dry or gelatine emulsion plates were beginning to be used with every promise of their ultimate value, as was shown by the photographs of the comet of 1881, which were made by Draper and Janssen. These were the first photographs ever made of a comet. Efforts had been made to secure pictures of Donati's comet in 1858, but without success.

It was quite obvious that as soon as satisfactory photographs of the stars were secured some earnest effort would be made to make use of them in a quantitative and systematic way. Previously, for the production of star maps and catalogues, elaborate series of observations were made at the various observatories and the positions of the stars computed and incorporated in large volumes. At the Royal Observatory at the Cape of Good Hope Sir David Gill, in 1882, after making some pictures with a large camera of the comet of that year, found that not only did the plate show the stars visible to the naked eye, but a number as small as the ninth or tenth magnitude. Accordingly it occurred to him that such photographs furnished a novel and excellent method of cataloguing the stars and mapping the heavens, as it was necessary only to measure on the glass negatives the positions of the various stars and refer them to certain well-known points of reference. From 1887 to 1891 the entire southern heavens from 18° south declination to the celestial pole were duly photographed. The half million stars found on the negatives were then measured and the magnitude of each determined by Professor J. C. Kapteyn at the University of Groningen, Holland. Thus in 1899

was finished the Cape photographic "Durchmusterung," which is published in three quarto volumes and contains the magnitude and approximate position of every star photographed, the magnitude of the stars on each plate being reduced to a visual scale.

At the time when Sir David Gill began his photographic work, Dr. Barnard states, "the Henry brothers of Paris were making a chart of the stars along the ecliptic in their search for planetoids. They had at this time reached the region of the Milky Way, and the marvelous wealth of stars they encountered on entering the boundaries of that vast zone completely discouraged them from carrying their charts through the rich region traversed by the ecliptic. While hesitating as to the advisability of continuing their work, the photographs of the great comet came to their notice. They were struck with the great number of stars shown on these pictures together with the image of the comet. The idea at once occurred to them that they could use this wonderful process to make their charts. They began at once the construction, with their own hands, of a suitable photographic telescope of 13½ inches diameter for the photography of the stars. This instrument produced exquisite star pictures, which were marvels of definition, as well as photographs of the nebula, of Saturn and Jupiter, the Moon, etc."

It was the success of the Henry brothers' work that led to the International Astro-Photographic Congress, which met at Paris in 1886. This Congress undertook the organization of an International Commission engaged in the preparation of a photographic chart and catalogue of the heavens, and the work since that time has been actively in progress. Uniform instruments of the same aperture and focal length are used at the eighteen observatories participating in this work and two sets of plates are being made, one to include all the stars that are capable of being photographed and the other one those of the eleventh magnitude. With this photographic map astronomers anywhere can compile their own catalogues, and portions of such catalogues by various national observatories have already been issued. The method of preparing the chart consists in photographing the whole sky upon glass plates about 8 inches square. Each observatory has had assigned to it definitely its part of the sky, and about 11,000 plates of the size specified will be required to complete the task. Each plate carries one or more well determined catalogue stars. The Great European War, in part, delayed the consummation of this task, which, when completed, will be the most complete record to date.

"The photographic plate not only did away with the necessity of making the star charts by eye and hand, so essential to facilitate the discovery of planetoids, but it also did away with necessity of the charts themselves for that purpose. The little planet, which is moving

among the stars, now registers its own discovery by leaving a short trail—its path during the exposure—on the photographic plate. The first of these photographic discoveries of planetoids was made by Dr. Max Wolf in 1892, and his observatory at Heidelberg subsequently became a headquarters for discoveries of this kind. Planetoids are now found wholesale in this manner by photography."

In the early days of photography nebulæ were considered the most unpromising subject for the photographic plate to deal with. Most of these objects appeared so faint that but little encouragement in that direction was offered the celestial photographer.

"One of the brightest and most promising of nebulæ is that in the sword of Orion, and this was naturally one of the first of these objects to receive photographic attention. In September, 1880, Dr. Henry Draper began photographing nebulæ with this object, and succeeded, with 51 minutes exposure, in getting a good picture of the brighter portions of dry plates. This was the first nebular photograph. It was followed by other photographs, one of which showed stars down to the 14.7 magnitude which were visually beyond the reach of the same telescope. These pictures marked a new era in the study of nebulæ. When the results were communicated to the French Academy by Dr. Draper, Janssen took up the work with a reflecting telescope having a silver-on-glass mirror of very short focus, constructed in 1870 for the total solar eclipse of 1871. With this Janssen found it easy to photograph the brightest parts of a nebula with comparatively short exposures. Unfortunately for science, the death of Dr. Draper, in 1882, put a stop in America to the work he had inaugurated, but it was at once taken up in England by Common, who, with a 3-foot reflector, attained rapid and immediate success. His photographs of the great nebula of Orion are still classic. They were a great advance over the work of Draper, for the reflector was not only a larger telescope, but was also better adapted for photographic purposes, and especially for photographing nebulæ. In fact, as we shall see in a later chapter on nebulæ, much of the progress in their study has been due to photography."

The photography of neubulæ was carried on with remarkable success at Lick Observatory during the incumbency of Professor James E. Keller as Director. Using the Crossley reflecting telescope, presented to the Observatory by Dr. Common, he made a photographic study of nebulæ, and reached the conclusion that there are at least 120,000 of the spiral type within the range of this instrument. Professor Perrine, who succeeded to this work on the death of Professor Keeler, believes that half a million is nearer the figure, but actually, there are only a few thousands that may be accounted as definitely known.

Not only stellar motion, but stellar distances, can be measured by photography. Professor Pritchard, at Oxford, has used the sensitive plate to sound the celestial depths. His first experiments were undertaken with the star 61 Cygni, and by measuring 200 negatives which had been made in 1886 he derived for that star a parallax of 0.438″, which was in satisfactory agreement with Ball's value of 0.468″. This work was subjected to detailed scrutiny, and the Astronomer Royal was convinced that it was more accurate than that of Bessel's results, obtained with the heliometer. This was the beginning of the method of measuring a parallax from photographic plates. Professor Kapteyn showed in 1889 that from such plates, exposed at desired intervals, parallaxes could be derived wholesale. He applied his system in 1900 to a group of 248 stars with encouraging success. In fact, it was suggested that a photographic parallax "Durchmusterung" should be undertaken after the completion of the astrographical chart of the heavens.

When used in connection with the spectroscope the photographic plate has a field singularly suited to display its possibilities. Here it deals not alone with what can be seen, but it enters into regions where the eye takes no cognizance of things. For tho it is partly blind to the light which affects the eye, it can readily penetrate the regions where man, in turn, is blind. By special treatment of the plate photography registers those rays invisible to the eye and permits their accurate measurement.

The spectrograph, or combination of photographic apparatus with spectroscope, must be so arranged as to show with distinctness the greatest number of lines, the individual lines being separated; consequently there are various types of spectrograph, depending upon the purpose for which they are to be employed.

One of the combinations of the spectroscope with the photographic apparatus is found in Professor Hale's spectroheliograph, which consists of a spectroscope across whose slit the solar image moves at a uniform speed. Instead of the eyepiece there is a second slit which permits light from only a single line to pass and fall on the moving photographic plate, so that an image of the Sun, or a sun spot in light of a single wave length, can be made to fall upon the plate and thus be recorded.

The general effect of photography in astronomy may be summarized in the brief statement that it has romoved the astronomer from the eyepiece of the telescope and has substituted the more sensitive photographic plate with its permanent record. "Hence it is that the present-day student of astrophysics does not correspond with the traditional idea of the astronomer," says Professor Hale. "His work at the telescope is largely confined to such tasks as keeping a star at the

precise intersection of two cross-hairs, or on the narrow slit of a spectrograph, in order that stars and nebulæ, or their spectra, may be sharply recorded upon the photographic plate. His most interesting work is done, and most of his discoveries are made, when the plates have been developed and are subjected to long study under the microscope."

CHAPTER V

THE LAW OF GRAVITATION

WHEN the astronomers of old tried to account for the apparent motions of the heavenly bodies by complete systems of epicycles, they must surely have asked themselves, Why do the planets move so regularly? What makes them move thus? If they did, they troubled themselves but little to answer the inquiries in anything but a perfunctory way. For the most part they were content to regard the stars as the playthings of divinity, and the cause of their motions, therefore, as a mystery forever veiled to human eyes. Still one astronomer, Anaxagoras, did have some idea of a force which holds the planets in their orbits and which might be the same as that which operates upon substances at the surface of the Earth.

After his day (499 [?]-427 [?] B.C.) the idea seems not to have been expressed by any one until the awakening of science in the seventeenth century. Then Kepler darkly hinted at some attractive force, because his discovery of the mathematical curve described by the planets seemed to demand the existence of some constantly exerted controlling force and also because he had read Gilbert's "De Magnete," in which he was made acquainted with the phenomena of electrical attraction.

Such a force as he had in mind would act to maintain the motion of the planets and to drive them along in their orbits. But this was hardly the solution of the problem, since as Galileo found, the motion of a body of itself must continue indefinitely, unless there is some cause at work to alter or stop it. This formed the first and most important of the laws of motion which, if not independently discovered by Newton, were subsequently to be stated by him with greater force and conciseness. The laws were of primary importance, because they afforded a new and correct way of considering not only the underlying reasons for the motions of the planets but of all mechanical problems involving matter and motion.

Aside from the three great laws of planetary motion established by Kepler as the result of many observations, the most important lesson taught by him, and one that was readily learned by Newton, was that the motions of the planets were not to be attributed to the influence of mere geometrical points, such as the centers of the old epicycles, but to the actual presence of other bodies. Kepler sug-

gested, in particular, that the planets might be considered as connected with the Sun and therefore as sharing to some extent the Sun's motion of revolution. From the Sun emanated that special kind of influence which he assumed. Yet, while Kepler considered the Sun as the source of this hypothetical force, he believed in a more general gravity or attraction between bodies.

He was unfortunate enough, however, to conceive of it diminishing simply in proportion to the distance between the two bodies, a mathematical impossibility, as was demonstrated by Newton. This is the more surprising as he had demonstrated that the intensity of light was reciprocally proportional to the surface over which it was spread and that it varied inversely as the square of the distance from the luminous body. It was also unfortunate that, while Kepler's ideas of the nature of gravity were sound and accurate in many respects, they bore no particular logical connection either one with another or with his theory of planetary motion. They are, however, worthy of comment as indicating the situation before Newton took these and other speculative ideas and the three isolated laws of planetary motion and bound them together into one beautiful doctrine which must underlie all astronomical science.

Kepler in his work, "Commentaries on the Motions of Mars," definitely states that gravity is a corporal affection, reciprocal between two bodies of the same kind, which tends, like the action of a magnet, to bring them together. When the Earth attracts a stone, the stone at the same time attracts the Earth, but by a force feebler in proportion as it contains a smaller quantity of matter. He then proceeds to state that if the Moon and the Earth were not retained in their respective orbits by an animal or other equipollent force, the Earth would mount upward the Moon one-fifty-fourth part of the interval which separates the two and the Moon would descend the fifty-three remaining parts, supposing it to have the same density. This idea of gravity, according to Kepler, was indeed general and served to explain the cause of the tides, as is clearly indicated in the following passage:

> "If the Earth ceased to attract its waters, the whole sea would mount up and unite itself with the Moon. The sphere of the attracting force of the Moon extends even to the Earth and draws the waters toward the torrid zone, so that they rise to the point which is the Moon in the zenith."

After Kepler had promulgated his famous laws of planetary motion many minds independently conceived a force to account for the remarkable uniformity of that motion. Thus the idea occurred to Robert Hooke, to Christopher Wren and perhaps to Edmund Halley, who was Newton's most intimate friend and who probably did more than

any other man of his time to popularize the idea of universal gravitation. It remained for the towering genius of Sir Isaac Newton (1643-1727) to formulate into a mathematical law of gravitation the effect of that universal force with which every schoolboy is now acquainted. The honor of having anticipated Newton was claimed by Hooke, and the two entered into an acrimonious controversy. Hooke never brought forward convincing proof of his claims. So far as Newton is concerned, the great merit of his work lay not so much in conceiving the law of gravitation as in his brilliant demonstration of its truth.

Starting with Kepler's laws of planetary motion, he showed not only that they were true, which was hardly a task of merit after Kepler had considered the observations of Tycho Brahe and all other astronomers whose recorded observations would throw any light on the subject, but why these laws were true, and why no other laws could have accounted for the conditions actually observed in the motion of the planets. And, furthermore, underlying these famous planetary laws he discovered must be the attraction of gravitation. By a mathematical analysis unrivaled in the history of astronomy he proved his theorem completely. Not only did he suggest, as did Kepler, that the power of attraction resided in the Sun, but he proved mathematically that as a necessary consequence of that attraction every planet must revolve in an elliptical orbit around the Sun, having the Sun as one focus; that the radius of the planet's orbit must sweep over equal areas in equal times and that in comparing the movements of two planets it is necessary that the squares of the periodic times be proportional to the cubes of the mean distances. These facts were discovered by Kepler; they were explained by Newton, with the aid of the powerful and celebrated mathematical reasoning which he had created. The explanation was the law of gravitation.

It occurred to Newton that if a diagram of the path of the Moon for any given period, say one minute, be made, it would be found that the Moon departs from a straight line during that period by a measurable distance. In other words, the Moon has been virtually pulled toward the Earth by an amount that is represented by the difference between its actual position at the end of the minute and the position it would occupy had it moved in a straight line, which according to Galileo's law of motion, it should follow unless some external force deflected it. By measuring the amount of deflection, he had a basis for determining the amount of the deflecting force. This deflection Newton found by his calculation to be thirteen feet. Obviously the force that acted on the Moon made it fall toward the Earth a distance of thirteen feet during the first minute of its fall.

Galileo had shown that the rapidity of a body's fall to the Earth

increased at a uniform rate—what is now termed the acceleration of gravity. In other words, the higher the starting point of the fall, the greater will be the final velocity. Hence the amount of the attracting force is in some way related to the distance between the two bodies, a relation which Newton expressed by stating that the falling body is attracted to the Earth by a force which varies inversely as the square of the distance between them.

If the attracting force then varies inversely as the square of the distance, would the Moon drop toward the Earth at the calculated rate of thirteen feet in the first minute? That was the problem which presented itself to Newton. The mathematical solution was simple, based as it was on a comparison of the Moon's distance with the length of the Earth's radius. Unfortunately there were no accurate dimensions of the Earth available when Newton made his first calculation in 1666. Hence he found, on the basis of the erroneous data at his disposal, that the Moon fell toward the Earth fifteen instead of thirteen feet during the first minute, a discrepancy so great that he dismissed the matter from his mind.

When in 1682 his attention was called to a new and apparently accurate measurement of a degree of the Earth's meridian made by the French astronomer Picard, he attacked the problem anew. As he proceeded with his computation it became more and more certain that this time the result harmonized with the observed facts. So completely was he overwhelmed that he was forced to ask a friend to complete the simple calculation. When the computation was ended it was known that the force which causes bodies to fall to the Earth extends outward to the Moon, and that by reason of this force the Moon circles around the Earth.

It required but a slight stretch of the imagination to assume that a force which can span the distance between the Earth and the Moon may also span the distance from the Sun to the Earth and the other members of the solar system. That such is really the case, Newton proved by a mathematical calculation of the orbital motions of Jupiter's satellites and of the various planets.

These discoveries and fundamental principles enunciated by Newton were elaborated with great exactness in his "Principia," and the section which discusses the motions of the Moon, confessedly one of the most difficult problems in celestial mechanics, has been termed by Sir George Airy the greatest chapter on physical science ever written. That it has stood the test of time is demonstrated by the fact that Newton's results have scarcely been extended in the centuries which have elapsed since their publication. The entire work is a marvel of exact mathematical reasoning by "the greatest genius the world has ever produced," according to Lagrange's estimate of Newton's intellectual powers.

Galileo had experimentally shown before Newton that the rate at which two bodies fall to the ground from equal heights is independent of their weights. A mass of gold and a mass of lead, altho of unequal weight, reach the Earth at the same time if dropped simultaneously from the same height. Newton repeated the experiment very exactly. He realized as a result that weight (gravitation) is constant. But because a pound of lead weighs less than two pounds of lead (in other words, is attracted with one-half the force) merely for the reason that it contains less matter, he was forced to the conclusion that gravitation is dependent upon quantity of matter as well as distance. Thus he introduced the very difficult conception of mass as distinguished from weight, or the force of attraction exerted on it by the Earth. The former, of course, is absolute and constant, but the latter varies with the position of the material in question on the Earth's surface or elsewhere in the universe.

If the mass of Venus is seven times that of Mars, then the force with which the Sun attracts Venus is seven times as great as that with which it would attract Mars if placed at the same distance; and therefore also the force with which Venus attracts the Sun is seven times as great as that with which Mars would attract the Sun if at an equal distance from it. Hence, in all cases of attraction, the force is proportional not only to the mass of the attracted body, but also to that of the attracting body as well as being inversely proportional to the square of the distance. Gravitation thus appears no longer as a property peculiar to the central body of a revolving system, but as belonging to a planet in just the same way as to the Sun, and to the Moon, or to a stone in just the same way as to the Earth.

Moreover, the fact that separate bodies on the surface of the Earth are attracted by the Earth and therefore in turn attract it, suggests that this power of attracting other bodies, which the celestial bodies are shown to possess, does not belong to each celestial body as a whole, but to the separate particles of which it is composed; so that, for example, the force with which Jupiter and the Sun attract each other is the result of compounding the forces with which the separate particles making up Jupiter attract the separate particles making up the Sun. Thus is suggested finally the law of gravitation in its most general form: "Every particle of matter attracts every other particle with a force proportional to the mass of each an inversely proportional to the square of the distance between them."

When Newton completed his "Principia" astronomy became in the fullest sense an exact science. Given the positions, velocities and motions of the Sun, Earth, Moon and other planets, then the manner in which they interact on one another can be learned and even their form and dimensions determined. In short, astronomy, from a more or less mystical science became in earnest a mathematical science.

When the motions and orbits of heavenly bodies were once observed, the positions of these bodies could be computed for future epochs.

In his "Principia" Newton confines himself to the demonstration of the laws of gravitation. He says nothing about the means by which bodies are made to gravitate toward each other. His mind did not rest at this point. He felt that gravitation itself must be capable of being explained. It is known that he even suggested an explanation depending on the action of an ethereal medium pervading space. But with that wise moderation which is characteristic of all his investigations, he distinguished such speculations from what he had established by observation and demonstration and excluded from his "Principia" all mention of the cause of gravitation, reserving his thoughts on this subject for the "Queries" printed at the end of his "Opticks." The attempts which have been made since the time of Newton to solve this difficult question are few in number and have not yet led to any well-established result.

CHAPTER VI

THE SOLAR SYSTEM—PLANETARY DISTANCES

To THE ancients as well as the moderns the Sun and the Moon appeared not only the largest but the most important of all the celestial bodies. With the Sun and Moon five other conspicuous spheres eventually were linked, spheres distinguished by reason of their regular motions. These orbs, Mercury, Venus, Mars, Jupiter and Saturn, were named "planets" or "wanderers" to distinguish them from the "fixed" stars.

Venus, familiar as the evening star or the morning star, was discovered—it was claimed—by Pythagoras in the sixth century B.C., but even in the poems of Homer there are references to both stars without any indication of their identity. Jupiter, Venus, Mars and Saturn, ranking with the brightest of the stars, and Mercury, occasionally seen near the horizon just after sunset or before sunrise, all were known to the ancients. A study of their movements naturally led to the obvious conclusion that all these moving stars or planets were related in some way and that the motion of one was more or less dependent on the motions of the others. Hence it may be asserted that the ancient history of astronomy begins with the system of planets that revolve around the Sun.

What is the nature of these planets? Obviously they are not all alike in size or distance. Even to the naked eye their appearance seems to reveal conditions that need explanation. Early observation and study revealed the fact that the planets occupied a section of the heavens where there were no so-called "fixed" stars. But later observation also revealed that, associated with the planets, are a number of smaller bodies of much the same nature known as "planetoids," or "asteroids," which, with a single exception, occupy the zone of the heavens between Mars and Jupiter. Lastly there are a large number of temporary visitors to this solar system known as the "comets." They plunge in from space, sweep around the sun and drift away by various paths or orbits, most of them never to return.

Planets, satellites, planetoids and comets comprise the Solar System. Vast and marvelously complete as that system is, it must be admitted that it is but a part of the great universe. It may be, as there is some reason to suppose, that this Solar System is but one of many similar

systems scattered throughout the universe and that each of these—including that in which the Earth is situate—is in turn wheeling about some central orb inexpressibly distant. The Solar System to which the Earth belongs is merely a type and not a unique example of planetary order.

The intellectual rise in Astronomy is nowhere more clearly revealed than in the history of man's conception of the Solar System. Perhaps the first inquiry that must have flashed across the mind of a thinking Chaldean or Greek concerned itself with the distances of the heavenly bodies. How far away are the planets? How is their distance measured? The second question concerned itself with their motions, Whither do they drift and why? Around these questions cluster a group of vague guesses, fruitless speculations and poetic fancies, from which at last a scientific method was evolved for measuring planetary distances and accounting for planetary movements. It was not until comparatively late in astronomical history that means were devised for ascertaining the physical condition of each planet.

The distances of the planets, small as they seem in comparison with sidereal measurements, are felt to be immense. Using only round numbers, which are sufficiently accurate for the present purpose, the planet Neptune, the outermost known member of our system, is 2,800,000,000 miles from the Sun. In a cord twenty-eight feet long each single foot will represent a hundred million miles. On such a scale a map of the United States could not be seen without the aid of a microscope. Suppose a bead were placed at each end of this line, one representing the Sun, the other Neptune. Between the two, other beads will represent the other planets. One nearly four inches from that representing the Sun will be Mercury; another, at about seven inches, Venus; a third, at eleven inches, the Earth; a fourth, at seventeen inches, Mars; a fifth, at about five feet, Jupiter; a sixth, at nine feet, Saturn; a seventh, at eighteen feet, Uranus, and an eighth, Neptune, at the end.

The mean distances of the planets from the Sun are as follows:

	MILES.
Mercury	36,000,000
Venus	67,200,000
Earth	92,900,000
Mars	141,500,000
Jupiter	483,300,000
Saturn	886,000,000
Uranus	1,781,900,000
Neptune	2,791,600,000

Attempts to measure some of these distances approximately are

found in early times. The idea that some of the planets must be nearer the Earth than others must have been suggested by eclipses and occultations—*i.e.*, passage of the Moon over the Sun and over a planet or fixed star. No direct means being available for determining the distance, rapidity of motion anciently was employed as a test of probable nearness. The stars being seen above, it was but natural to think of the most distant celestial bodies as the highest, and accordingly Saturn, Jupiter and Mars, being beyond the Sun, were called "superior planets" as distinguished from the two "inferior planets," Venus and Mercury. Uranus and Neptune are modern additions to the solar system and could not have been included in the hypothesis. Aristotle (384-322 B.C.), for example, arrived at the conclusion that the planets are farther off than the Sun and Moon as the result of an occultation of Mars by the Moon and as the result of similar observations made in the case of other planets by the Egyptians and Babylonians. Ptolemy (second century A.D.), altho far more original and daring in his astronomical conceptions than Aristotle, was able to add but little toward a solution of the problem. He expressly states that he had no means of estimating numerically the distances of the planets or even of knowing the order of the distance of the several planets. He followed tradition in conjecturally accepting rapidity of motion as a test of nearness and placed Mars, Jupiter, Saturn (which perform the circuit of the celestial sphere in about 2, 12 and 29 years, respectively) beyond the Sun in that order. As Venus and Mercury accompany the Sun, and may therefore be regarded as on the average performing their revolutions in a year, the test to some extent failed in their case, but Ptolemy again accepted the opinion of the "ancient mathematicians" —probably the Chaldeans—that Mercury and Venus lie between the Sun and Moon, Mercury being the nearer to the Earth.

Copernicus gave the first glimpse of the truth. To quote Berry in his "Short History of Astronomy": "From the fact that Venus and Mercury were never seen very far from the Sun, it could be inferred that their paths were nearer to the Sun than that of the Earth, Mercury being the nearer to the Sun of the two, because never seen so far from it in the sky as Venus. The other three planets, being seen at times in a direction opposite to that of the Sun, must necessarily revolve round the Sun in orbits larger than that of the Earth, a view confirmed by the fact that they were brightest when opposite the Sun (in which positions they would be nearest to us). The order of their respective distances from the Sun could be at once inferred from the disturbing effects produced on their apparent motions by the motion of the Earth. Saturn being least affected, must on the whole be farthest from the Earth, Jupiter next and Mars next. The Earth thus became one of six planets revolving round the Sun, the order

of distance—Mercury, Venus, Earth, Mars, Jupiter, Saturn—being also in accordance with the rates of motion round the Sun, Mercury performing its revolution most rapidly (in about 88 days), Saturn most slowly (in about 30 years)."

It was not until John Kepler (1571-1630) published his "Epitome of the Copernican Astronomy," his "Harmony of the World" and a treatise on "Comets" that astronomers were given a definite formula which enabled them to determine planetary distances with any exactitude. Kepler's speculative and mystic temperament led him constantly to search for relations between the various numerical quantities occurring in the Solar System. By a happy inspiration he tried to discover a relation between the sizes of the orbits of the various planets and their times of revolution round the Sun. After a number of unsuccessful attempts he discovered a simple and important relation commonly known as Kepler's third law:

> "The squares of the times of revolution of any two planets (including the Earth) about the Sun are proportional to the cubes of their mean distances from the Sun."

In other words, given the periods, there is need only to find the interval between any two of them in order to infer at once the distance separating them all from one another and from the Sun. Here was the plan. What was next to be discovered was the scale upon which the plan was to be drawn. There must be first a trustworthy measure of the distance of a single planet from the Sun, the Earth, for example, and the problem would be solved.

How is this measure to be obtained? Sir Robert Ball in his "Story of the Heavens," gives this simple example for partial explanation: "Stand near a window where you can look at buildings . . . or at any distant object. Place on the glass a thin strip of paper vertically in the middle of one of the panes. Close the right eye and note with the left eye the position of the strip of paper relatively to the objects in the background. Then, while still remaining in the same position, close the left eye and again observe the position of the strip of paper with the right eye. You will find that the position of the paper on the background has changed.

"Move closer to the window and repeat the observation, and you find that the apparent displacement of the strip increases. Move away from the window and the displacement decreases. Move to the other side of the room, the displacement is much less, tho probably still visible. We thus see that the change in the apparent place of the strip of paper, as viewed with the right eye or the left eye, varies in amount as the distance changes; but it varies in the opposite way to the distance, for as either becomes greater the other becomes less.

We can thus associate with each particular distance a corresponding particular displacement. From this it will be easy to infer that, if we have the means of measuring the amount of displacement, then we have the means of calculating the distance from the observer to the window. It is this principle applied on a gigantic scale which enables us to measure the distances of the heavenly bodies.

"Look, for instance, at the planet Venus; let this correspond to the strip of paper and let the Sun, on which Venus is seen in the act of transit, be the background. Instead of the two eyes of the observer, we now place two observatories in distant regions of the Earth; we look at Venus from one observatory, we also look at it from the other; we measure the amount of displacement and from that we calculate the distance of the planet. All depends, then, on the means which we have of measuring the displacement of Venus as viewed from the two different stations."

Two observers standing upon the Earth must be some thousands of miles apart in order to see the position of the Moon altered with regard to the starry background to obtain the necessary data upon which to ground their calculations. The change of positions thus offered by one side of the Earth's surface at a time is not sufficient, however, to displace any but the nearest celestial bodies. When there is occasion to go farther afield, a greater change of place must be sought. This can be obtained as a consequence of the Earth's movement around the Sun. Observations, taken several days apart, will show the effect of the Earth's change of place during the interval upon the positions of the other bodies of our system. But when the depths of space beyond are to be sounded and an effort is made to reach out for the purpose of measuring the distance of the nearest star the utmost change of place is necessitated. This results from the long journey of many millions of miles which the Earth performs around the Sun during the course of each year. Still, even this last change of place, great as it seems in comparison with terrestrial measurements, was insufficient to show anything more than the tiniest displacements in a paltry two hundred (1916) out of the entire host of stars. Three observatories are working in this direction by photography: the Yerkes, the Leander McCormick and the Allegheny.

It is thus readily realized with what an enormous disadvantage the ancients coped. The measuring instruments at their command were utterly inadequate to detect such small displacements. It was reserved for the telescope to reveal them, and even then it required the great telescopes of recent times to show the slight changes in the position of the nearer stars which were caused by the Earth's being at one time at one end of its orbit and some six months later at the other end—stations separated by a gulf of about 186,000,000 miles.

It was from an opposition of Mars observed in 1672 by John

Richer (?-1696) at Cayenne in concert with Giovanni Domenico Cassini at Paris that the first scientific estimate of the Sun's distance was derived. The Sun appeared to be nearly 87,000,000 miles away. John Flamsteed (1646-1720), the first Astronomer Royal of England, deduced 81,700,000 from his independent observations of the same occurrence. Jean Picard's (1620-1682) later result was just one-half Flamsteed's (41,000,000). Philippe De Lahire thought that the Earth must be separated from the Sun by at least 136,000,000 miles. The transits of Venus in 1761 and 1769 were employed, after other attempts had been made, to measure the Sun's distance.

The transit of 1769 is of particular interest, not only for a fairly good determination of the Sun's distance, but also for the reason that the celebrated Captain Cook was commissioned to sail to Otaheite for the purpose of witnessing the transit of Venus. At Otaheite, on June 3d, the phenomenon was carefully observed and measured. Simultaneously with these observations others were obtained in Europe and elsewhere. From a combination of all the observations, an approximate knowledge of the Sun's distance was gained. The most complete discussion of these observations did not, however, take place for some time. It was not until the year 1824 that the illustrious Johann Franz Encke computed the distance of the Sun and gave as the definite result 95,000,000 miles. Later Urbain Jean Joseph Le Verrier (1870) reduced the estimate to 91,320,000 miles, which held good until Prof. Simon Newcomb in 1882 gave the figure 92,475,000 miles. In 1900 nearly all the observatories of the world under the direction of Maurice Loewy and the French Academy of Science began a new computation which will lead to more exact results. The old problem of measuring a planet's distance from the Sun is not yet completely solved. If Sir David Gill's plan of basing a new set of calculations on the opposition of Eros in 1931 is carried into execution, the Sun's distance will be ascertained to within 10,000 miles. Present knowledge declares the distance of the planets from the Sun with an error not exceeding one-fiftieth of one per cent.

CHAPTER VII

THE SOLAR SYSTEM—THE MOTIONS OF THE PLANETS

THE motions of the planets also formed the basis for archaic theorizing. That the planets move, the ancients were fully aware, for the very word "planet" means "wanderer." The strip of the celestial sphere through which moves the Sun, the Moon and the five planets known to the ancients (Mercury, Venus, Mars, Jupiter and Saturn) was called the Zodiac, because the constellations in it were named after living things, with one exception. The Zodiac was divided into twelve equal parts, the "signs of the Zodiac," through one of which the Sun passed every month, so that its position could be roughly given by stating in what sign it was. The stars in each sign were formed into a constellation, the sign and constellation each receiving the same name. The relative movements of the planets as the ancients conceived them are thus summarized by Berry: "In Pythagoras occurs perhaps for the first time an idea which had an extremely important influence on ancient and medieval astronomy. Not only were the stars supposed to be attached to a crystal sphere, which revolved daily on an axis through the Earth, but each of the seven planets (the Sun and Moon being included) moved on a sphere of its own. The distances of these spheres from the Earth were fixed in accordance with certain speculative notions of Pythagoras as to numbers and music; hence the spheres as they revolved produced harmonious sounds which specially gifted persons might at times hear. This is the origin of the idea of the music of the spheres which recurs continually in medieval speculation and is found occasionally in modern literature. At a later stage these spheres of Pythagoras were developed into a scientific representation of the motions of the celestial bodies, which remained the basis of astronomy till the time of Kepler."

Philolaus, the Pythagorean, who lived about a century after his master, introduced for the first time the idea of the motion of the Earth. He appears to have regarded the Earth, as well as the Sun, Moon and five planets, as revolving round some central fire, the Earth rotating on its own axis as it revolved, apparently in order to insure that the central fire should always remain invisible to the inhabitants of the known part of the Earth. Altho pure fancy, the idea of Philolaus was a valuable contribution to astronomical thought.

Despite the immense influence of the Pythagoreans, most Greeks shared Plato's idea that any careful study of celestial motions was degrading rather than elevating, for the whole subject smacked too much of the unesthetic section of geometry. Still, Plato (429-347 B.C.) did give a short account of the celestial bodies, according to which the Sun, Moon, planets and fixed stars revolve on eight concentric and closely fitting wheels or circles around an axis passing through the Earth.

This idea of Plato's was more or less followed by later philosophers. Thus Eudoxus of Cnidus (409-356 B.C.) attempted to explain the more obvious peculiarities of planetary motion by means of a combination of uniform circular motions. The celestial motions were to some extent explained by means of a system of 27 spheres, 1 for the stars, 6 for the Sun and Moon, 20 for the planets. There is no clear evidence that Eudoxus made any serious attempt to arrange either the size or the time of revolution of the spheres so as to produce a precise agreement with the observed motion of the celestial bodies, tho he knew with considerable accuracy the time required by each planet to return to the same position with respect to the Sun; in other words, his scheme represented the celestial motions qualitatively but not quantitatively.

Aristotle adopted this scheme of Eudoxus, but needlessly complicated it by treating the spheres as material bodies and added 22 more spheres, thus making 49 in all. He argued against the possibility of the Earth's revolving around the Sun on the ground that there ought to be a corresponding apparent motion of the stars, an objection finally disposed of only during the nineteenth century, when it was discovered that this motion can be seen only in a few cases because of the unutterably great distance of the stars.

No substantial advance can be noted until Hipparchus (160-125 B.C.) made an extensive series of observations with all the accuracy that his instruments would permit and critically made use of old observations for comparison with later ones so as to discover astronomical changes too slow to be detected in a single lifetime—an essentially modern method. He systematically employed a geometrical scheme (that of eccentrics and epicycles) for the representations of the motions of the Sun and the Moon, a mode suggested in substance by Apollonius of Perga, who flourished in the third century B.C.

The great services rendered to astronomy by Hipparchus can hardly be better expressed than in the words of the great French historian of astronomy, Delambre, who is in general no lenient critic: "When we consider all that Hipparchus invented or perfected and reflect upon the number of his works and the mass of calculations which they imply, we must regard him as one of the most astonishing men of antiquity and as the greatest of all in the sciences which are not purely

speculative and which require a combination of geometrical knowledge with a knowledge of phenomena to be observed only by diligent attention and refined instruments."

The last great name encountered in tracing the record of changing conceptions of planetary motions is that of Ptolemy (100-170 A.D.), whose reputation rests on his "Almagest," which may be regarded as the astronomical gospel of the Middle Ages. Hipparchus, as we have seen, found the current representation of the planetary motions inaccurate and collected a number of new observations. These, with fresh observations of his own, Ptolemy employed in order to construct an improved planetary system. Following the idea of Hipparchus, Ptolemy thought that the Sun and Moon moved in circular orbits around the Earth as a center. Ptolemy's chief work was to expand the system of epicycles so that it could explain discrepancies between theory and observation, discrepancies overlooked or ignored by Hipparchus. The deviations of the planets for the ecliptic, for example, were accounted for by tilting up the planes of the epicycles. Thus with the aid of the system of Hipparchus, supplemented with his own idea of tilting epicycles, he worked out with great care and labor the motions of the planets. Altho the Hipparchian-Ptolemaic doctrine was framed on an extravagant estimate of the importance of the Earth in the scheme of the heavens, yet it must be admitted that the apparent movements of the celestial bodies were thus accounted for with considerable accuracy. For fourteen centuries the Almagest was regarded as the final authority on all questions of astronomy and it may be considered as the loftiest piece of calculation pertaining to the Ancient World.

CHAPTER VIII

THE SOLAR SYSTEM—MODERN INVESTIGATION

THE Ptolemaic system of astronomy was discredited only at an epoch nearly simultaneous with that of the discovery of the New World by Columbus. The true arrangement of the solar system was then expounded by Nicholas Copernicus (1473-1543) in the great work, "De Revolutionibus," to which he devoted his life. The first principle established by these labors showed the diurnal movement of the heavens to be due to the rotation of the Earth on its axis. Copernicus pointed out the fundamental difference between real motions and apparent motions. He proved that the appearances presented in the daily rising and setting of the Sun and the stars could be accounted for by the supposition that the Earth rotated, just as satisfactorily as by the more cumbrous supposition of Hipparchus and Ptolemy. He showed, moreover, that if the ancient supposition were true, the stars must have an almost infinite velocity and declared that the rotation of the entire universe around the Earth was clearly preposterous.

The second great principle, which has conferred immortal glory upon Copernicus, assigned to the Earth its true position in the universe. Copernicus transferred the center, about which all the planets revolve, from the Earth to the Sun, and he established the somewhat crushing truth that the Earth is merely a planet, pursuing a track between the paths of Venus and of Mars and subordinate like all the other planets to the supreme sway of the Sun. This great revolution swept from Astronomy those distorted views of the Earth's importance which arose, perhaps not unnaturally, from the fact that the observers chanced to live on this particular planet. Whether the actual services rendered by Copernicus are commensurate with his fame may be doubted. He labored under the weight of an ecclesiastical tradition that could not be abandoned without some risk. He was a bold man indeed who dared to overthrow or even to guestion orthodoxy and to diminish the Earth's overshadowing importance in the Solar System.

The Copernican system was not flawless either in theory or logic and many objections could be made to it, particularly by an astronomer who had observed and studied the movements of the heavenly bodies. After the example of the ancients, Copernicus as-

sumed as an axiom the uniform, circular motion of the planets, and, as the only motions which are in a state of incessant variation, he was obliged, in order to explain the inequalities to suppose a different center for each of the orbits. The Sun was placed within the orbit of each of the planets, but not in the center of any of them. In other words, he still adhered to a system of epicycles. Consequently the Sun performed no other office than to distribute light and heat. Excluded from any influence on the system, the Sun became a stranger to all the motions. The "fixed" stars were alleged to be stationary, and it was necessary to suppose that they were almost infinitely distant, inasmuch as they always seemed to preserve the same position when viewed from the opposite sides of the Earth's orbit.

While various astronomers showed some disposition to accept the Copernican teaching, most of them were bitterly opposed to it on ecclesiastical traditionary and scientific grounds. Tycho Brahe (1546-1601) was the most distinguished of these opponents. Being an indefatigable observer and practically the first to realize the value of continuous observation, he enriched astronomy by a star catalogue and studies of the movements of the other heavenly bodies. Tycho accepted the Copernican conception of a central Sun, but rejected the idea that the Earth moved. Thus he sought to effect a compromise between the Ptolemaic and Copernican systems. It was the study of a comet in 1517 that led Tycho to formulate his ideas of the solar system. He believed that the comet was revolving around the Sun at a distance greater than that of Venus and assumed that both the Sun and the Earth were centers of revolving systems, the five planets revolving around the Sun and the entire system in turn moving around the Earth. This incorrect proposition, which was one of the least of Tycho Brahe's contributions to astronomical science, is significant, showing as it does how difficult it was for the principles of Copernicus firmly to establish themselves and planetary motions to be explained satisfactorily.

Whatever Tycho may have thought of the Copernican system, his contemporary, Galileo (1564-1642), was willing to accept it. It has been shown how Galileo with the telescope of his own invention was able to extend astronomical science and to introduce new methods of observation, which came naturally to one who was a leader in the experimental science of his time. But even before his work with the telescope Galileo had adopted the astronomical views of Copernicus and collected arguments for their support. He was able in 1604 to confirm the discovery of Tycho Brahe that changes take place in the heavens beyond the planets and that there was an important region beyond the Earth and its immediate surroundings. As was but natural, the use of the telescope broadened Galileo's horizon, and, true

scientist that he was, he immediately brought to bear his new discoveries on the fundamental conceptions.

Thus his discovery of the satellites revolving around Jupiter as the planets themselves revolved around the Sun not only rendered necessary the explanation of these new bodies, but dealt a serious blow at the infallibility of Aristotle and Ptolemy, neither of whom had any idea of the existence of these satellites. Further support was given to the Copernican theory by the ocular demonstration of these satellites revolving around Jupiter and not dropping behind, just as the Moon was required to move around the Earth, a mechanical difficulty brought forward by the opponents of the Copernican idea. As Galileo developed his astronomical ideas and discoveries he naturally came into conflict with ecclesiastical authority and there began the unfortunate controversy as to the relative validity in scientific matters of observation and reasoning on the one hand and the authority of the Church and Bible on the other.

Controversies such as this were conspicuous in the latter part of Galileo's life. They culminated in his famous trial and formal abjuration of his alleged errors and in his coviction "of believing and holding the doctrines—false and contrary to the Holy and Divine Scriptures—that the Sun is the center of the world and that it does not move from east to west, and that the Earth does move and is not the center of the world; also that an opinion can be held and supported as probable after it has been declared and decreed contrary to the Holy Scriptures." Despite Galileo's abjuration, his general attitude toward the Church and the Bible is contained in his approval of the saying of Cardinal Baronius, "That the intention of the Holy Ghost is to teach us not how the heavens go, but how to go to heaven." His attempts to explain and demonstrate the Copernican system in his great astronomical treatise, "Dialog on the Two Chief Systems of the World, the Ptolemaic and Copernican," led to his trial and conviction, before the Inquisition.

Kepler, another of Galileo's contemporaries, did more even than the great Italian to bring about a proper conception of the solar system and the motions of the planets. A student under Tycho, it was but natural that Kepler should have imbibed from his master a respect for systematic observation, regardless of the correctness or incorrectness of Copernican views. As a result Kepler early adopted the Copernican doctrine, opposed tho it was by his master. His observations led him to the conclusion, however, that even Copernicus had not revealed all the mysteries of planetary motion and that the hypothetical circles in which the planets revolved around the Sun, according to Copernicus, did not agree with the paths observed. Under the instruction of Tycho, Kepler addressed himself to the problems involved in the planet Mars, whose positions as seen in the sky were a

combined result of its own motion and that of the Earth, as both move around the Sun. Actual observation of the planet and the consideration of various geometrical theories that suggested themselves eventually led to the conception that the path of the planet must be some form of an oval.

Finally Kepler reached the conclusion that instead of being circular, the planet's motion must lie in the simple curve known as an ellipse and formed by taking an oblique section of a cone. While the circle has but a single center, the ellipse depends for its form upon two fixed points, each of which is termed a focus. It can be drawn by using two pins stuck in a sheet of paper and by inserting a pencil within a loop of string that also includes the two pins. The curve may be traced by moving the pencil, while the string is kept taut. It will be found that if the two points are kept close together the curve approaches in form a circle, while if they are separated the figure becomes elongated and possesses what the mathematicians term greater eccentricity. At any rate, every point on the curve is such that the sum of its distance from the two foci is always the same. Kepler found that the Sun was at one focus. When the planet was near that focus, it moved with greater velocity than when at the opposite part of its orbit. The speed of motion, however, was always proportional to the areas swept out by a straight line from the Sun in equal intervals of time. In other words, there were formulated the now famous first and second laws of Kepler as follows:

1. The planet describes an ellipse, the Sun being in one focus.

2. The straight line joining the planet to the Sun sweeps out equal areas in any two equal intervals of time.

Kepler not only established these laws for Mars, but immediately applied his principle to the Earth and then claimed (without proof, however) in his "Epitome of the Copernican Astronomy" that these two fundamental laws applied also to all the planets and to the motions of the Moon. Accompanying these two laws was the third, already discussed, in which it is stated that the squares of the times of revolution of any two planets (including the Earth) about the Sun are proportional to the cubes of their mean distances from the Sun.

It was the disclosure of these wonderfully simple relations that laid the foundation for the Newtonian law of gravitation. Contemporary judgment, of course, could not anticipate the culmination of a later generation. What it could understand was that the first law of Kepler attacked one of the most time-honored of metaphysical conceptions—the Aristotelian idea that the circle is the perfect figure and that planetary motions consequently must be circular. Not even Copernicus had doubted the validity of this assumption.

Kepler was too great a genius to rest content with the mere observation that the planets move in ellipses. Next he desired to determine

why they do so move. It remained for Isaac Newton (1643-1727) to answer the question satisfactorily; yet Kepler had a curious premonition of the law of gravitation. "Whereas the Ptolemaic system," comments Berry, "required a number of motions round mere geometrical points, centers of epicycles or eccentrics, equants, etc., unoccupied by any real body, and many such motions were still required by Copernicus, Kepler's scheme of the solar system placed a real body, the Sun, at the most important point connected with the path of each planet and dealt similarly with the Moon's motion round the Earth and with that of the four satellites round Jupiter. Motions of revolution came in fact to be associated not with some 'central point' but with some 'central body,' and it became therefore an inquiry of interest to ascertain if there were any connection between the motion and the central body. The property possessed by a magnet of attracting a piece of iron at some little distance from it suggested a possible anology to Kepler, who had read with care and was evidently impressed by the treatise 'On the Magnet' ('De Magnete'), published in 1600 by William Gilbert of Colchester (1540-1603). He suggested that the planets might thus be regarded as sharing to some extent the Sun's own motion of revolution. In other words, a certain 'carrying virtue' spread out from the Sun, with or like the rays of light and heat, and tried to carry the planets round with the Sun." Kepler says himself in his "Epitome":

> "There is, therefore, a conflict between the carrying power of the Sun and the impotence or material sluggishness (inertia) of the planet; each enjoys some measure of victory, for the former moves the planet from its position and the latter frees the planet's body to some extent from the bonds in which it is thus held, . . . but only to be captured again by another portion of this rotatory virtue."

Thus is faintly indicated the great theory of gravitation which, as developed by Newton, was to supply a satisfactory explanation of planetary motion and which is the underlying basis of all modern astronomy.

Newton had become convinced that the attracting power of the Earth extended even to the Moon, and that the acceleration produced in any body—whether it be as distant as the Moon or close to the Earth—was inversely proportional to the square of the distance from the Earth's center and also proportional to the mass of the body. Then he found that the motions of the planets could be explained by an attraction toward the Sun, which produced an acceleration inversely proportional to the square of the distance from the center of the Sun, not only in the same planet in different parts of its path but also in different planets.

Again it follows from this that the Sun attracts any planet with a force inversely proportional to the square of the distance of the planet from the Sun's center and also proportional to the mass of the planet. Accordingly, if the Earth or Sun attracts a body, the body must exert a similar force on the Earth or the Sun, and gravitation is not only a property of the central body of a revolving system, but belongs to every planet in just the same way as to the Sun and to a Moon or to a stone just as to the earth.

After Newton had established provisionally the law of gravitation and the laws of motion, it remained for him to prove that the observed motions of the planets agreed with those calculated. A situation of the greatest complexity, however, was relieved by the fact that the mass of even the largest planets is so very much less than that of the Sun that the motion of any single planet is affected but slightly by the others, and it may be assumed to be moving very nearly as it would if the other planets did not exist, due allowance being made subsequently for minor disturbances or perturbations produced in its path. One by one the various irregularities observed were explained, and the motion of the Moon and its various eccentricities were computed with accurate numerical results.

For many years the solar system remained in its fancied integrity. There was no change in the original five planets and the number of satellites first discovered by Galileo and added to by subsequent observers had reached an apparent culmination when G. D. Cassini (1625-1712) had detected the second pair of satellites of Saturn in 1684. Accordingly, when Herschel, following his custom of making a review of the heavens with each new telescope that he constructed, found March 13, 1781, with a Newtonian telescope, seven feet in length, a small star which appeared so much larger than its companions and of such uncommon appearance, he suspected it to be a comet. Further study revealed that it was more than a comet and of far greater interest. When heedfully observed and its path calculated, it was found that no ordinary cometary orbit would in any way fit its motion.

Anders Johann Lexell (1740-1784) first recognized that Herschel's body was not a comet but a new planet revolving around the Sun in a nearly circular path and at a distance about nineteen times that of the Earth and nearly double that of Saturn. A vain attempt by Herschel to name the new planet after his royal patron, George III., "Georgium Sidus," finally resulted in the proposal and acceptance by British and continental astronomers alike of the name Uranus, which harmonized with the names of the other planets.

This discovery was of especial interest, inasmuch as Johann Daniel Titius (?-1796), a professor at Wittenberg, had pointed out the remarkable symmetry in the disposition of the planets. In a note,

published in 1772, he showed that the distance of the six known planets from the Sun could be represented with a close approach to accuracy by a certain series of numbers increasing in the regular progression, 0, 3, 6, 12, 24, 48, etc. Adding 4 to each number, the results would give the relative distances of the six known planets from the Sun. In applying this law (which does not hold good in the case of Neptune) it was found that the term of the series following that which corresponded with the orbit of Mars was not represented in the list of planets. Accordingly Johann Elbert Bode (1747-1826), a German astronomer, assumed a hypothetical planet to take this place. When Uranus was discovered its distance was found to fall but slightly short of perfect conformity with the law of Titius, and it stimulated the search for a new body, which, as will be seen in the chapter on the planetoids, proved to be the small planet Ceres.

The study of Uranus after its discovery by Herschel furnished many difficulties to astronomers. Despite the most careful calculations of the movements of the planet through more than a century's observations, the conclusion was reached that considerable errors existed or that the planet was wandering from its course. In fact, these disturbances had aroused the interest of several mathematicians and astronomers, and a young English student, John Couch Adams (1819-1892), soon after his graduation from Cambridge, communicated in 1845 to the Astronomer Royal numerical estimates of the elements and orbits of the unknown planet which he assumed was acting on Uranus and was the cause of the disturbances. In fact, he indicated the actual place in the heavens of the hypothetical planet. At practically the same time a French astronomer, Urbain Leverrier (1811-1877), who had made a careful study of the solar system in response to a request from Dominique F. J. Arago, the head of the French Observatory, prepared an elaborate memoir in which he demonstrated that only an exterior body could produce the disturbances observed and that such a body must occupy a certain and determinate position in the zodiac. He also assigned the orbit of the disturbing body, indicating that it would be as visible and bright as a star of the eighth magnitude. In fact, he supplied data to Professor Galle, of the Berlin Observatory, which enabled that astronomer to find in the heavens on September 23, 1846, within less than a degree of the spot indicated an object with a measurable disk. A reasonably complete map of this portion of the sky, in which all the stars were noted, proved beyond question that the object was not a star, while its movement as predicted was ample confirmation of its planetary nature. Adams' work, which antedated that of Leverrier, had not received attention originally in Great Britain at the hands of the Astronomer Royal, but as the matter assumed importance the

Cambridge Observatory also participated in the search and on September 29, 1846, the planet was seen again. Thus Neptune was discovered. To show the rapidity of astronomical research in the nineteenth century it may be remarked that it required but seventeen days for the discovery of a satellite by Lassell (1799-1880) with a two-foot reflecting telescope.

Astronomers have suspected the existence of still other planets, and the belief has been expressed that such a body exists nearer to the Sun than Mercury, which, as has been seen, enjoys the reputation of being the closest of all the planets to the central luminary. The average distance of Mercury from the Sun is about 36,000,000 miles, so that there would be space enough for such a planet. Its peculiar position in close proximity to the Sun, however, would act against its being observed. A small luminous point in this position would be altogether invisible, even with the best modern telescope, while its setting and rising, simultaneous almost with those of the Sun, make it invisible at these times even under the most favorable conditions. If this planet should pass across the Sun's disk just as do Mercury and Venus, it would be seen. While from its size it would be much less of a spectacle than the two planets mentioned, it might be detected. Claims have been advanced by astronomers that they have seen such a transit of a small spot.

The first suggestion of an intra-Mercurial planet came from the distinugished French astronomer, Leverrier, who in 1859 advanced such a hypothesis in an attempt to explain the movements of the planet Mercury. His theory involved a body of about the size of Mercury revolving at somewhat less than half its mean distance from the Sun, or at a greater distance if of less mass and vice versa, whose motion in great part would explain the irregularities observed. In the same year Dr. Lescarbault at Orgères maintained that he had observed such a body crossing the Sun's disk, and the name of Vulcan was bestowed upon it. Several astronomers claimed to have seen the new planet. Their observations were not well authenticated, and on the dates fixed for the probable transits no trace of the planet could be found. The strongest test was the examination of the sky at the time of a solar eclipse, for then the light of the Sun was cut off and a strange body could be readily identified. Despite a careful watch at subsequent eclipses and an examination of photographic plates, only negative results have been obtained. To-day the belief that there is any body of considerable size within the orbit of Mercury is held by a few astronomers and very guardedly stated.

If the search for an intra-Mercurial planet was unsuccessful, it has in no way deterred astronomers from endeavoring to find other unrecognized members of the solar system. Much interest has

been arroused by a hypothetical ultra-Neptunian planet, which of course would be the furthest from the Sun of all the members of the solar system. The basis for such a hypothesis is the reduction of observations made of the positions and motions of Uranus and Neptune. Neptune has been under observation for only a small part of a revolution, so that data thus far obtained seem to many astronomers insufficient for the purpose. Yet a number of astronomers have sought by calculation to prove the existence of such a planet. While their results are discordant, yet they indicate very closely the regions of the sky where search for the hypothetical body might be rewarded with success.

Professor W. H. Pickering, of Harvard, in 1909 evolved a method for the discovery of the distant planet, a method which he first tested by application of the data available to Adams and Leverrier for the discovery of Neptune, and found that the method would succeed. Proceeding then with his hypothetical planet, which he termed "O," he found that it was 51.9 times as far distant from the Sun as the Earth, tho its mass was but twice that of this planet, and that it had a period of revolution of 373.5 years. The problem presented by Uranus, Neptune and "O," according to Professor Pickering, is quite the same as that of Mercury, Venus and the Earth, which has been thoroly studied, so that the relative motions are well understood.

But in investigating the effect that such a hypothetical planet would have on the motion of Uranus, Professor A. Gaillot recently arrived at the conclusion that there were indications pointing to the possibility of still another and more distant planet also exercising a perturbing influence. The results of his calculations and studies therefore indicate the possible existence of two ultra-Neptunian planets, one at a distance from the Sun equal to 44 times the Earth's mean distance and having a mass about 1/64,000 the mass of the Sun, the other having a distance 66 times that of the Earth and a mass about 1/14,000 that of the Sun. While these figures disagree with those of Professor Pickering, yet the position calculated for the second planet agrees quite closely with that of the Harvard astronomer. The problem is by no means solved. It is mentioned to show that a plausible case has been made out for at least one ultra-Neptunian planet.

After astronomers had definitely decided how far the planets and the Sun are situated from the Earth and how they move with respect to one another, they began to wonder if perhaps the whole solar system did not in turn revolve around some central orb. The possibility first occurred to Tobias Mayer (1726), John Michel (1767) and Joseph Jérome Le François Lalande (1776), but the problem was not attacked with any degree of success until Sir

William Herschel in 1782 began to draw conclusions from his study of the Milky Way and decided that the entire solar system was drifting toward the constellation Hercules. But Herschel's theory did not meet with general acceptance for many years. Other astronomers suggested various stars as possible central suns controlling the movement of our Solar System. Thus Mädler not only proposed that Alcyone, the principal star in the Pleiades, should be the central sun, because of its situation at a point of neutralization of opposing tendencies and consequently at rest, but even went so far beyond the limits of astronomy as to declare that "Here was the seat of the Almighty, the Mansion of the Eternal." It is hard even for science to quell the imagination and to confine an observer to facts. Mädler's theory was short-lived. Further study of the stars demonstrated the soundness of Herschel's views.

When a modern telescope is turned toward the Milky Way this white girdle of the celestial sphere is resolved into a vast number of stars which more than 140,000,000 already have been counted on photographs. Each of these stars is a sun like that which governs the Earth, probably surrounded by planets like the Earth, and all these solar systems also are moving, many of them more swiftly than ours.

It was inferred from Herschel's measurements of stellar positions, distances and motions that the solar system was situated comparatively near the center of a universe shaped like a thin, double-convex lens. This universe was supposed to rotate as a unit about its center, with the result that the Sun (comparatively near that center, but absolutely at an immense distance from it) moved in a circle of dimensions so vast that since the discovery of its motion it had not deviated appreciably from a straight line, but had steadily directed its course toward the constellation Hercules.

This simple scheme must now be abandoned, for it has been discovered by Professor J. C. Kapteyn, a Dutch astronomer, that the visible universe consists of two distinct parts. The scientific imagination is compelled to picture two processions of stars moving in paths which make an angle of 115 degrees with each other. One of these stellar streams moves three times as fast as the other. The Sun forms a part of one of the streams and is at present at their intersection. It is proceeding on a direct line for the bright star Vega in the constellation Lyra at a speed of 720 miles a minute or over half a million miles a year, carrying the solar system (including the earth) with it. Yet, so inconceivably vast are the distances in space that the fifty million miles covered in a century form so small a fraction of the distance as almost to be unnoticeable.

Altho it is known in a general way that the entire solar system is moving through space at the rate of 12 miles a second, the shape and

size of the Sun's orbit are utterly unknown. The changes of environment, accordingly, that will accompany the description of it defy conjecture. The actual course of the solar system is inclined at a small angle to the plane of the Milky Way. Presumably it will become deflected, but perhaps not sufficiently to keep the system clear of entanglement with the galactic star-throngs. In the present ignorance of their composition, no forecast of the results can be attempted; they are uncertain and exorbitantly remote. Hence in a sense, the world knows where it is and in what direction it is moving. But what is the goal, when shall it be reached and what will happen then? Or, in this crossing of the congested thoroughfares of the heavens, will the world be shattered by a collision and resolved into a glowing nebula? This has been the fate of many stars, of several within the period of human history and of one—Nova Persei—within a few years and witnessed in all its destructive detail by astronomers still living. Other novae since that time—four since Nova Persei—have recapitulated the story.

CHAPTER IX

THE SUN—: ECLIPSES; SUN-SPOTS AND AURORÆ; THE PHOTOSPHERE

THE preëminence of the Sun among the celestial bodies and its obvious importance to the life of the world has given to it a unique place, not only in astronomy but in philosophy and religion. The rising of the Sun and the light that it casts over the Earth are distinctly symbolical of the conquest of light over darkness or the triumph of truth over error, so that in many schemes of mythology the Sun god assumes the highest rank and rules over the other elements, such as the Moon, the rains and floods and the stars. Of this there are abundant instances in all primitive religions. Among the Oriental nations, to whom we owe the idea of a flood from which the world emerged, the Sun god reigned supreme. In Egypt, among the Chaldeans and Babylonians and later among the Greeks and Romans the Sun held like sway. In Persia, Sun Worship was developed into a more formal religion, which survived for many years.

After the mind of man had developed to a point where it was concerned with philosophical speculation rather than with the mysticism handed down by the priesthood, there came a desire to understand the relation of the Sun to the Earth and to the universe. Its motion across the sky was obvious as well as its change of position from time to time. On this, as has been seen, various theories were founded. It was early realized that the Sun described an annual path on the celestial sphere, which path is a great circle, and this great circle, known as the ecliptic because eclipses take place only when the Moon is in or near it, is at an angle to the equator of the sphere. This angle is termed the obliquity of the ecliptic and was measured by the Chinese, it is claimed, as early as 100 B.C. with remarkable accuracy. Later the same feat was claimed for Pythagoras or Anaximander in the sixth century B.C., both of whom probably derived their information from the Chaldeans or Egyptians.

When the Sun crosses the equator the day is equal to the night, which occurs twice a year, at the vernal equinox about March 21 and the autumnal equinox about September 23. When the Sun is at its greatest distance from the equator on the north side the time is known as the summer solstice, and when at its greatest distance on the south side it is termed the winter solstice. The positions of

these points in the heavens were also known to the early Chinese astronomers with considerable accuracy, while Anaximander, who supposed the Sun to be of equal magnitude with the Earth, used a gnomon or vertical pillar casting a shadow to observe the solstices and equinoxes.

Anaximenes is said to have believed that the Sun was a mass of red-hot iron or of heated stone somewhat larger than the Peloponnesus. He looked upon the heavens as a vault of stones, prevented from falling by the rapidity of its circular motion, while the Sun could not proceed beyond the tropics on account of a thick and dense atmosphere which compelled it to retrace its course. Later Philolaus of Crotona, who was a disciple of Pythagoras and followed his master's teaching that the Earth revolved about the Sun, assumed that the Sun was a disk of glass which reflected the light of the universe. Eudoxus of Cnidus, about 370 B.C., stated that the diameter of the Sun was nine times greater than that of the Moon, which marked a triumph over the illusions of sense. About the time of Alexander, the Great Pytheas, using the gnomon, determined the length of the shadows cast at the summer solstice in various countries. His observations are the most ancient of those preserved after those made in China.

The study of the Sun was undertaken very systematically by Hipparchus, who discovered that the solar orbit was eccentric and that the Sun moved at different speeds at different parts of its journey. With his observational data Hipparchus produced the first tables of the Sun which are mentioned in astronomy. He was enabled to determine the difference between the solar day or time as shown by the Sun and the time indicated by some such measuring device as the clepsydra or water-clock.

The motion of the Sun was also studied by Ptolemy. He compiled solar tables more extensive than those of Hipparchus, which were employed until Albategni (b. 815) made a new compilation of greater accuracy, and which served as a connecting link between the astronomers of Alexandria and those of modern Europe. The obliquity of the ecliptic was constantly being studied. Ulugh Begh, a Tartar prince and grandson of the great Tamerlane, at Samarkand, using a gnomon 100 feet in height, determined the obliquity of the ecliptic or precession of the equinoxes, and secured data for the construction of astronomical tables which were of considerable accuracy.

The apparent motions of the Sun furnished many difficult problems for the astronomer, since the observational data lacked accuracy on account of the absence of satisfactory instruments. Measuring angles by the shadow cast and positions in the sky by crude forms of angular measurement were not adequate for exact work. Not until the advent of the quadrant and the telescope with its various ad-

juncts was scientific measurement possible. But there were from time to time solar eclipses, of which a careful record was maintained and which the ancient priests noted in connection with their calendar observations. These eclipses played a most important part in ancient astronomy.

An eclipse of the Sun occurs when Earth, Moon and Sun are in direct line at the time of new Moon. As the latter lies between the Earth and the Sun its dark body will pass across the Sun's disk, cutting off the direct illumination. If the Earth cuts off the sunlight from the Moon there is a lunar eclipse. Solar eclipses are of three kinds, partial, annular and total. In the first the Moon, instead of passing directly between the Earth and the Sun, slips past on one side and cuts off from sight only a portion of the Sun's surface. In the annular eclipse the Moon is centrally interposed between the Sun and the Earth, but falls short of the apparent size required to conceal the solar disk entirely. Consequently at the height of obscuration a bright ring is visible around the Moon. In a total eclipse, however, the Sun completely disappears behind the dark body of the moon. The difference between a total and an annular eclipse depends upon the fact that the apparent diameters of the Sun and the Moon are so nearly equal as to preponderate alternately one over the other through the slight periodical changes in their respective distances from the Earth.

It is the total eclipse that particularly arouses the attention of astronomers, for it cuts off entirely the light of the Sun, and in addition to enabling the observation of the various parts of its surface as it passes across its disk to be made, also makes it possible for an observer to see the stars and planets in the daytime even if they are very near the Sun. A total eclipse of the Sun is not visible on the entire Earth, but only along a comparatively narrow band, lying roughly from west to east and measuring about 165 miles in width. A partial eclipse is seen for about 2,000 miles on either side of this band, but otherwise the phenomenon is not visible on the Earth's surface.

Chinese records going back over 4,000 years describe a solar eclipse which occurred during the twenty-second century B.C. That eclipse carried with it a distinct moral lesson. Two bibulous state astronomers, Ho and Hi, unfortunately happened to be drunk on the day of its occurrence and hence incapable of supervising the performance of the required rites, which consisted in beating drums, shooting arrows and other ceremonies intended to frighten away the mighty dragon who was about to swallow up the Lord of Day. Altho the eclipse was only partial, nevertheless great confusion resulted, and Ho and Hi were put to death as a lesson to later astronomers.

Another early record of a total eclipse comes from Babylon, 1063 B.C. Several centuries later Assyrian tablets record solar eclipses. Herodotus, Plutarch and the Bible all refer to the phenomenon. Thus one is enabled to determine with accuracy the time of historical events. Likewise in the Anglo-Saxon chronicles several notable eclipses are recorded.

The Sun appears as a brilliant white body. Just as the Earth is enveloped by an atmosphere, so the Sun is surrounded by several layers of gaseous and vaporous matter, with the result that so far as an observer on the Earth is concerned its nucleus is quite invisible. These layers are more or less transparent, just as the atmosphere of the Earth is transparent, so that the bright white body of the Sun is visible only through these various envelopes. This bright white portion is called the photosphere and is the source of the light and heat which is radiated to the Earth. Here are found the sun-spots distinctly seen with the telescope and even by the naked eye. Under the photosphere it may be that the more solid portions of the Sun are situated, but it is obvious that its surface consists of highly incandescent vapors above which is a smoke-like haze. Upon this rests the reversing layer, which is composed of glowing gases, but is cooler than the photosphere beneath. It has a thickness of between 500 and 1,000 miles and contains, as the spectroscope shows, many of the elements of which the Earth is composed, in the form of vapor. Above the reversing layer comes the chromosphere. The chromosphere is between 5,000 and 10,000 miles in thickness and is composed of glowing gases, chief among which is hydrogen. The chromosphere is a brilliant scarlet in hue, but the redness is entirely overpowered by the intense white light of the photosphere, which shows through from behind. The most interesting features of the chromosphere are the red prominences, which are the marks of violent agitation in its upper portions and which are such a notable feature in total solar eclipses. After the chromosphere comes the corona, which is the outer envelope of the Sun and consists of a halo of pearly white light of irregular outline which fades away into the surrounding sky and extends outward for many millions of miles. The corona suffers so much from the brilliancy of the photosphere that it is only on the occasion of a total solar eclipse that it can be seen in all its remarkable beauty.

As the photosphere, the reversing layer and the chromosphere are all sources of light, the solar spectrum observed in spectroscopes is composed of the three separate spectra combined. For this reason eclipses afford welcome opportunities for studying the Sun's surface. When the Moon completely covers the photosphere its brilliant light is cut off and other features of the Sun can be examined visually, and, what is more important, spectroscopically and photograph-

ically. Thus when the spectroscope is directed to the reversing layer during a total eclipse the dark lines of the solar spectrum change into bright lines or are reversed. But this reverse spectrum is a phenomenon of a moment only, and as the Moon progresses an altered spectrum is obtained. That of the chromosphere is of sufficiently long duration to permit an estimate of its depth and nature, and finally, when this is covered up, there is the corona, which which has a distinct spectrum of its own, containing a strange line, the distinguishing green of which has not yet been identified with any element known upon the Earth.

Modern conceptions of the Sun are due very largely to the use of the telescope, the spectroscope and the spectroheliograph, especially the last two instruments. With the telescope, when the intense light of the Sun is properly reduced, it is possible to examine its surface and obtain a certain amount of information as to its nature or to obtain photographs of that surface by very short exposures. But on the spectroscope and the spectroheliograph the astronomer depends for his knowledge of the constitution and composition of the great center of the solar system. The development and nature of the spectroscope, as used in solar research, have been already discussed, but it is appropriate to add here a brief explanation of the spectroheliograph, for to its use is due not only a large part of present-day information of the prominences, but more recently an explanation of the sun-spots themselves and the study of various features of the photosphere.

The spectroheliograph was first devised in successful working form by Prof. George E. Hale at Kenwood Observatory, Chicago, in 1889. "The principle of this instrument is very simple," writes Professor Hale. "Its object is to build up on a photographic plate a picture of the solar flames by recording side by side images of the bright spectral lines which characterize the luminous gases. In the first place, an image of the Sun is formed by a telescope on the slit of a spectroscope. The light of the Sun after transmission through the spectroscope is spread out into a long band of color, crossed by lines representing the various elements. At points where the slit of the spectroscope happens to intersect a gaseous prominence the bright lines of hydrogen and helium may be seen extending from the base of the prominence to its outer boundary. If a series of such lines corresponding to different positions of the slit on the image of the prominence were registered side by side on a photographic plate, it is obvious that they would give a representation of the form of the prominence itself.

"To accomplish this result it is necessary to cause the solar image to move at a uniform rate across the first slit of the spectroscope. and, with the aid of a second slit (which occupies the place of the

ordinary eye-piece of the spectroscope), to isolate one of the lines, permitting the light from this line and from no other portion of the spectrum to pass through the second slit to a photographic plate. If the plate be moved at the same speed with which the solar image passes across the first slit, an image of the prominence will be recorded upon it." The same method answers for the study of the sun-spots and other features of the Sun's surface. As the result of telescopic, spectroscopic and spectroheliographic observation it is now known that the Sun's principal features are its sun-spots, its photosphere, its chromosphere and its corona.

A sun-spot when examined through a telescope consists of a dark central region called the umbra into which long, narrow filaments reach. The space occupied by these filaments is termed the penumbra. The darkness of the umbra is not absolute, but is relative to the more brilliant surface of the photosphere, and if observed alone would be far more brilliant than the most powerful arc light. These dark spots on the Sun were familiar objects in the days of pretelescopic observation. But their importance to astronomy dates with their discovery in 1610 by Galileo with his telescope. The great Italian astronomer did not announce his discovery until May, 1612, by which time sun-spots had been seen independently by Thomas Harriott (1560-1621), John Fabricus (1587-1615), who published his observations in June, 1611, or before Galileo, and the Jesuit Father Christopher Scheiner (1575-1650), all of them pioneer observers with the telescope.

Before sun-spots were clearly observed with the telescope it was assumed that they were due to the transit of Mercury. Even Father Scheiner, after his telescopic studies, suggested that the spots might be small planets revolving around the Sun and appearing as dark objects whenever they passed between the Sun and the observer. It was recognized, however, that the spots appeared to move across the face of the Sun from the eastern to the western side, or roughly from left to right. Father Scheiner's view was also held by Jean Tarde, Canon of Sarlat; by Father Malpertius, a Belgian Jesuit, and later by William Gascoigne, the inventor of the micrometer. Galileo, however, advanced a cloud theory, while Simon Marius, "astronomer and physician" to the brother Margraves of Brandenburg, proposed the ingenious "slag theory," according to which the dark spots were the cindery refuse of a great solar conflagration and occasionally expelled in the form of comets, which afterward blazed up with renewed vigor. Galileo in a controversy with Father Scheiner proved him wrong in his planetary theory, while the occurrence of comets in 1618 won supporters for the theory of Marius. Galileo also ascertained the rotation of the Sun in a period of between 25 and 26 days, as well as the general zone of the sun-spots.

The next important contribution to sun-spot theory came from Derham, whose observations were made during the years 1703-1711. He believed that the spots on the Sun were caused by the action of some new volcano, whose smoke and other "opacous matter" produced the spots. As they decayed they became half shadows encircling the darker portions and finally became bright spots. Lalande, the celebrated French astronomer, believed that the spots were rocky elevations, about which the penumbra represented shoals or sandbanks, while around flowed enormous oceans. Lalande's explanation, as well as that of Derham, was clearly based upon terrestrial analogies, which were employed with considerable frequency by early astronomers.

In 1769 Alexander Wilson, of Glasgow (1714-1786), examining the large sun-spot visible that year, noted that, as the Sun's rotation carries a spot across its disk, there was a change in its appearance, and that the same effect of perspective was produced as if it were a saucer-shaped depression, the bottom forming the umbra or central black spot and the sloping sides the penumbra or surrounding portion of half shadow. The penumbra appeared narrowest on the side nearest the center of the Sun and widest on the part nearest the edge. Hence Wilson assumed "that the great and stupendous body of the Sun is made up of two kinds of matter, very different in their qualities, that by far their greater part is solid and dark, and that this immense and dark globe is encompassed by a thin covering of that resplendent substance from which the Sun would seem to derive the whole of his vivifying heat and energy." Wilson went on to explain that the excavation of spots might be occasioned "by the working of some sort of elastic vapor which is generated within the dark globe," and that the luminous material, which was more or less fluid, was acted upon by and tended to throw down and cover the nucleus.

Sir William Herschel devoted considerable attention to the Sun, and observing the variation in the sun-spots, reached the conclusion in 1801 that it indicated a certain variability in the total amount of solar radiation, which he assumed might have some connection with terrestrial phenomena, especially the weather. He endeavored first in 1801 to trace connection between the price of wheat, naturally influenced by the effect of weather on the crops, and the occurrence of sun-spots, claiming that when the latter were scarce there was a diminished solar activity, which caused cold weather, with obvious results. Ingenious as this theory was, there was not sufficient substantiating meteorological data. It finds, however, a counterpart in modern studies of the Sun's heat, not necessarily connected exclusively with sun-spots, however, whereby it is hoped to establish

some useful knowledge of the relation between the amount of heat radiated from the Sun and weather conditions on our Earth.

Herschel's observations of the Sun and sun-spots were continued by his son, Sir John Herschel, at the Cape of Good Hope (1836-1837). John Herschel assumed that their motion was due to fluid circulations similar to those producing the trade and anti-trade winds on the Earth. "The spots, in this view of the subject," he said, "would come to be assimilated to those regions on the Earth's surface where for the moment hurricanes and tornadoes prevail, the upper stratum being temporarily carried downward, displacing by its impetus the two strata of luminous matter beneath, the upper of course to a greater extent than the lower, and thus wholly or partially denuding the opaque surface of the Sun below."

Such observation of sun-spots, made with considerable thoroness by the astronomers mentioned, as well as numerous others, did not establish any regularity in their appearance or effacement. It remained for Heinrich Schwabe (1790-1875) at Dessau to announce in 1843 that the sun-spot phenomena reached a maximum probably in a decennial period. This announcement, altho coming as it did after a patient study of the Sun, attracted no particular attention until a series of sun-spot statistics were published in Humboldt's "Kosmos." Then the correctness of Schwabe's observations and deductions was apparent to all. When compared by Dr. John Lamont and Sir Edward Sabine with various periodical magnetic disturbances, it was found that the two cycles of changes agreed with extraordinary exactness. It was a remarkable coincidence that the observations of a number of investigators were in complete harmony. A study of the sun-spot records established the decennial period correctly at 11.11 years. Thus commenced a recognition that magnetic disturbances on the Earth were related in some way to sun-spot phenomena. For many years no direct connection could be established, altho various theories were forthcoming. Likewise further attempts were made to identify the variations of sun-spots with meteorological phenomena, but without success, until Wolf in 1859 by an examination of the Zürich chronicles (1000-1800 A.D.) found data which enabled occurrences of the Aurora Borealis to be correlated with a disturbed condition of the Sun.

From this time on the influence of the Sun on terrestrial conditions assumed new importance. The beautiful phenomenon of the aurora, which consists of a glow in the sky about the north and south poles, had been observed for ages, but the first scientific connection of importance recorded was in 1716, when Halley stated that the Northern Lights were due to magnetic "effluvia." In 1741 Hiorter at Upsala observed that they produced an agitation of the magnetic needle. This connection was further demonstrated by

Arago (1819), so that by the middle of the nineteenth century the connection of the Aurora with the Sun and in turn with terrestrial magnetism was as evident as it was insufficiently explained.

The first result of the modern study of the sun-spots was to put an end to the old notion that there was a dark and cold interior of the Sun and that the sun-spots were merely rents in the brilliant cloud covering through which the interior portion could be seen. The late Prof. S. P. Langley, one of the most active of the modern students of the Sun and its surface, thought that the filaments which, taken together, constitute the penumbra, were everywhere present on the surface. Professor Hale states: "He regarded them as resembling the stalks of a wheat-field, seen on end in the undisturbed photosphere, and revealing more of their true characteristics in the penumbra, where they are bent over and drawn out toward the central part of the spot. Langley believed that we are observing clouds of luminous vapors rising from the Sun's interior, the seats of convection currents which bring to the surface the immense supplies of heat radiated by the Sun into space. Separating these luminous columns are darker regions, characterized by a lower degree of radiation.

"The minute details can be recorded only with the greatest difficulty. Under ordinary atmospheric conditions the solar image is not seen as a sharp and well-defined object, but its details are continually blurred by the effect of irregularly heated currents in our atmosphere. Even under the best conditions the moments of very sharp definition are few, and the greatest patience and perseverance are required on the part of an observer who would record his impressions of the solar structure. At the best, drawings based upon visual observations must be unsatisfactory, since even the skilled hands of Langley could not secure the perfect precision which is so desirable. It accordingly might be hoped that here, as in other departments of solar research, photography would afford the necessary means of securing results unattainable by the eye. Unfortunately, however, this hope has been only partially realized."

The influence of sun-spots is not confined to magnetic and electrical phenomena. The researches of Köppen, which have been confirmed by Newcomb, show that the average temperature of the Earth determined by the combination of a great number of thermometric observations made at several stations indicated a fluctuation of 0.3° to 0.7° C. during the 11-year sun-spot period. In other words, the temperature of the Earth's atmosphere indicates small fluctuations which correspond with the sun-spot period, thus indicating that the solar heat radiation varies with the number of the sun-spots. The mean temperature of the Earth is greatest at the time of minimum sun-spots and lowest at time of maximum sun-spots. Hence the

determination of the amount of heat radiated by the Sun at various times, especially at sun-spot maxima and minima, is a matter of considerable terrestrial importance.

The study of the sun-spots carried on by Professor Hale with the spectroheliograph and other apparatus, including special red-sensitive plates of considerable speed, reached an interesting stage in 1908, when it was announced that sun-spots are centers of attraction which draw toward them the hydrogen of the solar atmosphere. Subsequently it was found that these spots are the seats of great cyclones, in which cool hydrogen gas is set whirling and is sucked down in the great maelstrom of the Sun, rushing into the center of the spot at a rate of about 60 miles a second. Consequently the spots are the center of great solar disturbances which are of an electro-magnetic nature. According to the modern electronomic theory of matter and electricity, "electrons," or minute particles of matter, in their terrific cyclonic velocity produce magnetic lines of force. It was found by Professor Zeeman that, when light is passed through a strong magnetic field, the lines of the spectrum are subdivided and appear double. This Zeeman effect Professor Hale has found in the spectrum of the sun-spots. If one looks at the center of a spot the light travels in the direction of the axis of the whirl or cyclone, while in viewing a spot at the edge of the Sun, the direction is at right angles to the axis and is manifested accordingly in the spectrum. This theory has been partly confirmed, so that to-day it is generally held that sun-spots are magnetic fields of great intensity. The important discoveries made by Professor Hale and his associates may thus be summarized as follows: First, that the spots are cooler than the surrounding region; second, that they may be centers of violent cyclones, and, third, that they are magnetic fields of great intensity.

In addition to the sun-spots the photosphere includes other interesting features, notable among which are the "faculæ," "little torches," so named by Father Scheiner. These bright, globular objects, besides the sun-spots, are the only other phenomena of the Sun's surface visible by direct observation. Schröter showed that the faculæ are heaped-up ridges of the disturbed photospheric matter. Secchi and Young assumed that the faculæ are the result of violent eruptive action of the sun-spots, but it remained for the spectroheliograph to give a clear idea of their nature. Professor Hale states that "they are usually most numerous in the vicinity of sun-spots, and near the Sun's limb they are sometimes very conspicuous brilliant objects covering large areas. Near the center of the Sun, however, they are practically invisible, tho faint traces of them can sometimes be made out on photographs taken with a suitable exposure. This increase of brightness toward the Sun's limb is assumed to be

due to the elevation of the faculæ above the photospheric level and their escape from a considerable part of that absorption which so materially reduces the brightness of the photosphere. Rising above the denser part of the absorbing veil and thus suffering but little diminuation of light, they appear near the Sun's limb as bright objects on a less luminous background. The chief difference of the faculæ from the rest of the photosphere lies in their greater altitude, as photographs have shown that they may be resolved into granular elements similar to those constituting the photosphere. But they are the regions from which immense masses of vapors rise to the solar surface and for that reason are important in the solar mechanism.

"Near the edge of the Sun their summits lie above the lower and denser part of that absorbing atmosphere which so greatly reduces the Sun's light near the limb, and in this region the faculæ may be seen visually. At times they may be traced to considerable distances from the limb, but as a rule they are inconspicuous or wholly invisible toward the central part of the solar disk. The Kenwood experiments had shown that the calcium vapor coincides closely in form and position with the faculæ, and hence the calcium clouds were long spoken of under this name. In the new work at the Yerkes Observatory the differences between the calcium clouds and the underlying faculæ became so marked that a distinctive name for the vaporous clouds appeared necessary. They were therefore designated flocculi, a name chosen without reference to their particular nature, but suggested by the flocculent appearance of the photographs."

"With the spectroheliograph," Professor Hale relates, "it was at once found possible to record the forms, not only of the brilliant clouds of calcium vapor associated with the faculæ and occurring in the vicinity of the sun-spots, but also of a reticulated structure extending over the entire surface of the Sun. . . . From a systematic study of spectroheliograph negatives, in the course of which the heliographic latitude and longitude of the calcium clouds, or flocculi, in many parts of the Sun's disk were measured from day to day (by Fox), a new determination of the rate of the solar rotation in various latitudes has been made. This shows that the calcium flocculi, like the sun-spots, complete a rotation in much shorter time at the solar equator than at points nearer the poles. In other words, the Sun does not rotate as a solid body would do, but rather like a ball of vapor, subject to laws which are not yet understood."

CHAPTER X

THE SUN—II: THE REVERSING LAYER; THE CHROMOSPHERE AND CORONA; RADIATION PRESSURE AND SOLAR ENERGY

THE so-called "reversing layer" was discovered by the late Professor Charles A. Young during the eclipse of December 22, 1870, on which occasion he placed the spectroscope with its slit tangential to the Sun's limb, so that it ran along a shallow bed of incandescent vapors. When the Moon reduced the size of the crescent of the Sun the dark lines of the spectrum and the spectrum itself gradually faded away until all at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was covered by bright lines more numerous than one could count. This phenomenon lasted for about two seconds and gave the impression of a distinct reversal of the Fraunhofer spectrum, showing bright lines for dark in every case. That such a reversing layer should exist was demanded by Kirchoff's theory of the production of the Fraunhofer lines, and implied a stratum of mixed vapors at a lower temperature than that of the surface of the Sun. It was by such a stratum that the missing rays of the solar spectrum were stopped. The spectrum from this portion alone should supply bright lines if the overpowering brilliancy of the solar background could be cut off, which can occur only at the time of an eclipse. This observation of Professor Young's, with its important bearing on the theory of Kirchöff, was not confirmed until 1896, when photographic evidence was forthcoming. During the eclipses of 1898 and 1900 abundant corroborative material was obtained, and the reversing layer as a reality was conclusively demonstrated. The total depth of this reversing layer has been placed at from 500 to 600 miles. It continues in a normal state of tranquillity, for little change is produced in the aspect of the dark lines.

The chromosphere or envelope of glowing gases which covers the Sun completely was detected by observers of eclipses in the eighteenth and nineteenth centuries. There is a record in a letter from Captain Stannyan to Flamsteed, the British Astronomer Royal, describing an eclipse witnessed at Berne on May 1 (O. S.), 1706, in which he states that the Sun's "getting out of the eclipse was preceded by a blood-red streak of light from its left limb." Halley and De Louville in 1715 noted a similar phenomena, and it was also observed

during annular eclipses of 1737 and 1748, but with the ruby brilliancy toned down to "brown" or "dusky red" by the surviving sunlight. During the eclipses of 1820, 1836 and 1838 similar observations were made, but it was not until the eclipse of the 8th of July, 1842, that the virtual discovery of the chromosphere as a solar appendage may be said to have been made. The eclipse of 1868, which was observed spectroscopically and photographically as well as with the telescope, served to make clear the nature of the chromosphere and to reveal that it is a continuous envelope of hydrogen and other incandescent gases, some thousands of miles in thickness and of the same eruptive nature as the prominences which are shot out from it In other words, it seems to be a collection of minute flames set close together and giving it the appearance of a large conflagration. The summits of the flames of fire, which incline when the Sun's activity is greatest, are erect during its phase of tranquillity.

The chromosphere is marked by an irregular distribution over the Sun's surface, which in no way partakes of the character of an atmosphere. Professor Hale in 1897 discovered a low stratum of carbon vapor. Such rare metals as gallium and scandium have been discovered with the spectroscope. The vapors of magnesium, iron and several other substances are conspicuously represented in the spectrum of the chromosphere, and with the Yerkes telescope the fine bright lines due to the vapor of carbon also may be seen.

The solar prominences are conspicuous eruptive or flame-like emanations from the chromosphere which are seen at total eclipses of the Sun. They project like red flames beyond the dark edge of the Moon, and were first described by Lector Vassenius, a Swedish professor of Gothenburg, who observed the total eclipse of May 2 (O. S.), 1733. One of these reddish clouds outside of the solar disk was so large that it could be detected with the naked eye. The phenomenon excited his admiration and wonder. The prominences were also observed in 1778 by the Spanish Admiral Don Antonio Ulloa, who was convinced of their connection with the Sun on account of their color and magnitude. By some observers the solar prominences were regarded as the illuminated summits of lunar mountains, and by Arago they were described as solar clouds shining by reflected light. Abbé Peytal, in 1842, spoke of them as self-luminous and as a third or outer solar envelope composed of the glowing substance of the bright rose tint which produced mountains, just as clouds were piled above the Earth's surface. In 1851 Hind, an English astronomer, noted on the south limb of the Moon "a long range of rose-colored flames," which Dawes spoke of as a low ridge of red prominences resembling in outline the tops of a very irregular range of hills. Airy also noted this rugged line of projections, and spoke of its brilliancy and "nearly scarlet" color. But the truly solar

origin of the phenomena was not conclusively demonstrated until 1860, when the prominences were photographed by Secchi and De la Rue, and shown to be independent of the motion of the Moon. In 1868, with the growth of spectroscopy and solar chemistry, the gaseous nature of the prominences and their connection with the Sun was made evident. They were found to consist of immense masses of hydrogen and helium gas rising from the chromosphere and reaching an altitude of hundreds of thousands of miles.

The Corona.—The corona is a beautiful lustrous solar wrapping, which can be observed only during a total eclipse. The winged circle, the winged disk, or the ring with wings, as it is variously called, found upon Assyrian and Egyptian monuments, may be reproductions of the phenomenon. The first definite mention of a solar corona is to be found in Plutarch, in connection with the eclipse which probably took place in 71 A.D. He writes that the obscuration caused by the Moon "has no time to last and no extensiveness, but some light shows itself around the Sun's circumference which does not allow the darkness to become deep and complete." Kepler mentions a ray of light seen around the eclipsed Sun in 1567, and ascribes it to some sort of luminous atmosphere around the Sun. In 1706 Cassini, observing an eclipse of the Sun in France, saw the "crown of pale light" around the lunar disk, and stated that it was caused by the illumination of the zodiacal light. Halley, observing an eclipse in London in 1715, describes minutely the phenomena of the luminous ring rising around the Moon to a great height, and showing considerable brilliancy. The eclipse of 1842 was the first to indicate the corona's great importance to astronomers, and from that date it received careful attention and earnest study.

In 1869 Professor Harkness and Professor Young discovered a bright line of unknown origin in the coronal spectrum, showing that it consists in large part of glowing gases. With the advent of astronomical photography, and with the development of the spectroscope, more attention than ever was given to the careful study of the corona in the limited time available on the occasion of a total eclipse. The corona is described by Professor Hale as a "faintly luminous veil of light extending outward in long streamers from the surface of the photosphere to distances of several millions of miles, and exceeded in brilliancy, even in its brightest parts, by the full Moon. In many ways its streamers resemble those of the Aurora Borealis, and it is indeed possible that their origin may be ascribed to some similar electrical cause. During the few minutes of a total eclipse they are not seen to undergo change or form but

the outline of the corona does vary greatly from year to year, in sympathy with the general variation of the solar activity.

"Spectroscopic observations have shown that the corona consists mainly of gases unknown to the chemist. That is to say, the lines in its spectrum do not coincide in position with the lines of any terrestrial element. Whether these gases, which are probably very light, will ultimately be found on the Earth cannot be predicted. Like helium, first known in the Sun, they may eventually be encountered in minute quantities in some mineral where they have hitherto escaped the chemist's analysis. The fact that the lower part of the corona gives a continuous spectrum, with a feebler solar spectrum superimposed upon it, indicates that minute incandescent particles are present, which are hot enough to radiate white light, and which scatter enough sunlight to account for the presence of the solar spectrum." The strange line in the green portion of the spectrum does not correspond with that of any element with which we are acquainted upon the Earth, and accordingly a hypothetical element has been assumed, to which the name of "Coronium" has been applied. In 1915 this "coronium" element was confirmed.

Chemical Composition.—Anaximenes' idea that the Sun was a glowing ball of incandescent iron came almost as near the truth as subsequent speculations by philosophers and astronomers, until about the middle of the nineteenth century. In 1859 Kirchoff's great discovery of the explanation of the Fraunhofer lines in the solar spectrum made it possible to ascertain the chemical composition of the Sun. Thus, as has been shown, the bright-colored band formed of light from a small hole in Newton's shutter passing through a prism made that prism the forerunner of an instrument able to teach the nature and constitution of bodies far distant in the heavens. Thomas Melvill had examined with a prism various flames in which different substances had been introduced, and had reached the conclusion by the middle of the eighteenth century that certain vapors, notably sodium, contained light which had a definite place in the spectrum. Melvill's deep yellow ray became the sodium line in the spectroscope of Fraunhofer.

When Kirchoff noted the identity of certain lines characteristic of terrestrial elements, and then assumed their presence in the Sun. he laid the foundation of the modern science of solar chemistry. Wherever light can be obtained from a heavenly body it is now possible to resolve it into its spectral elements and thus to identify the substances. In fact, as substances such as helium were found in the Sun by Lockyer, which had no terrestrial counterpart, hypothetical elements were assumed. The spectroscope has shown in the Sun the presence not only of gases such as hydrogen and helium, but iron, sodium, magnesium, calcium, and many other substances,

Hence the chemical composition of the Earth and the Sun are mu the same, altho there is evidence of existence in the Sun of substanc not yet found in the Earth. When the spectroscope was appli to the analysis of the chromosphere and its prominences it was four that they are composed of the vapor of calcium and of the light gas helium and hydrogen. Sun-spots, too, have been found to have characteristic chemical composition, while the corona emits rays whi probably indicate the presence in it of very light and tenuous gases.

With the light given off by the Sun there is to be considered phenomenon which only recently has been demonstrated by exper ment, namely, that light exerts a pressure which can act on minu particles quite as effectively as gravitation. Gravitation, howeve attracts entire masses, but pressure acts only on surfaces, so th a force such as the pressure of light, to be effective, must deal wit very minute masses. If you subdivide a mass into a large numb of minute particles the effect of gravitation is not changed, but point will be reached in the subdivision where particles may be ol tained having much surface and very little weight. If such a particl has a diameter of 1/100,000 of an inch it will be exactly balanced i space, pulled by gravitation (weight) on the one hand, pushed b light on the other. If the particle is even smaller than 1/100,000 of a inch in diameter the pressure of light upon it pushes it away wit terrific force. It is the radiation of the Sun acting on the minut particles that produces the phenomenon of comets' tails, and it i this pressure which may be responsible for the brilliant phenomen of the corona, visible only during the vanishing moments of a tot eclipse. No one has ever satisfactorily explained how the highl attenuated matter composing both the prominences and the coron is supported without falling back into the Sun under the pull o solar gravitation. Now that Arrhenius has cosmically applied th effects of light pressure a solution is presented.

How difficult it is to account for such delicate streamers a "prominences" on the Sun is better comprehended when we full understand how relentlessly powerful is the grip of solar gravitation The Sun admittedly projects vapors into space, vapors which mus condense into drops when they encounter the cold of outer space If the drops are larger than the critical size which determine whether light-pressure or gravitation shall prevail they will b snatched back by the Sun's gravitational attraction and give rise t the curved prominences that are often observed. If they have ap proximately the critical diameter they will float above the Sun in th form of beautiful carmine clouds, balanced in space by the equa and oppositely acting forces of gravitation and radiation pressure These clouds have hitherto been particularly puzzling, for in th absence of a dense solar atmosphere their existence seemed a celestia

paradox. If the condensed drops are smaller than the critical diameter they will be projected by the pressure of light far beyond the Sun, to form the beautiful pearly corona.

From the fact that comets have passed through the corona without any very apparent retardation, some idea of its tenuity may be gained. Assuming that the corona consists of particles of such size that the radiation pressure on each exactly equals its weight, Arrhenius finds that the entire corona weighs no more than 12,000,000 long tons, which is equivalent to four hundred large transatlantic steamers, and is not more than the amount of coal burned on the Earth every week.

Compared with the infinity of the space in which it is poised, the Earth is smaller than a vanishingly small speck on a sheet of paper having an area of many square miles. So far as the Earth is concerned, the Sun is very much in the position of a man who throws away all but a single cent of a fortune consisting of twenty-three million dollars; for only 1/2,300,000,000 of his radiated energy reaches this globe. What, then, becomes of the huge number of corpuscles which are shot from the Sun and which never strike the Earth? It is conceived by Arrhenius and his followers that many of them must collide with corpuscles discharged by suns other than that of this solar system—suns ineffably distant, so that their light reaches the Earth only after the lapse of countless centuries, and so that they are seen not as they gleam now, but as they gleamed when Egypt was young and Greece was a wilderness inhabited by savages. Such collisions must result in the formation of larger masses up to a limit determined by the electrical charges carried by the corpuscles.

Solar Energy.—The Earth depends upon the Sun for its supply of heat and light. The Sun is transmitting heat to the Earth, and unless the supply of energy is being replenished in some way it is obvious that it must be losing in heat and temperature. From its effect on the Earth an estimate can be had of the amount of heat radiated by the Sun annually. If it be assumed that the Sun has the same heat capacity as water, and hydrogen is the only substance with a greater heat capacity, it would fall in temperature about 4° F. annually. If, therefore, the great luminary were simply a hot body, cooling off, its present rate of radiation could not be maintained for more than 3,000 years. That the Sun has been radiating a much longer period than this is obvious from geological and biological evidence, so that some other cause must be sought.

Up to the nineteenth century the doctrine of infinite durability was generally held by astronomers and geologists. For that reason no particular attention was paid to the nature of the heat of the Sun and its source; but with the formulation of the doctrine of the

conservation of energy it was realized that the energy of the Earth must proceed from the Sun for the greater part, and consequently it became necessary in turn to question the source of solar heat. Robert Mayer, to whom is due the earliest conception of the conservation of energy, asked himself: If the Sun is hot, why does it not cool off? In 1848 Mayer published some answers to his own question in a paper which failed to receive the approval of the French Academy of Sciences. His conclusions were as follows: The Sun cannot be a glowing mass sending out radiation without compensation. Solar heat cannot be due entirely to chemical changes, nor can it be due to solar rotation. In his opinion it was the result of meteors falling into the Sun. He did not overlook the fact that the resulting increase in the mass of the Sun would increase its attraction for the planets and would shorten the sidereal year. This was contrary to the facts of observation, and Mayer was forced to an incorrect conception of the undulatory theory of light to explain the situation. Six years later William Thomson, subsequently Lord Kelvin, reached independently almost the same conclusion as Mayer, but he was able to explain the increase in the Sun's mass resulting from meteoric showers, for according to the gravitation theory the "added matter is drawn from space, where it acts on the planets with very nearly the same force as when incorporated in the Sun."

Lord Kelvin then ventured an estimate of the age of the Sun, which was the first attempt in this direction made by a physicist. He assumed that the solar energy of rotation was derived from the fallen meteors, which, allowing for the constant loss of solar energy by radiation, could be acquired in 32,000 years. Taking into consideration the limited amount of meteoric matter available near the Sun, he concluded that "sunlight cannot last as at present for three hundred thousand years." This theory attracted little attention when promulgated by him in 1854, and was abandoned by him later.

But in the same year Helmholtz, working along the lines of the nebular hypothesis of Kant and Laplace, derived the heat of the Sun from the contraction of the nebula from which the Sun and planets were formed. He asserted also a further contraction of the Sun, now assumed to be in progress, by which the kinetic energy obtained was converted into heat, and compensated for the loss of solar heat by radiation. Accordingly, if the Sun contracts one ten-thousandth part of its radius each year, enough heat would be generated to supply radiation for 2,100 years. Helmholtz' computation gives twenty-two million years as the probable age of the Sun, based on a uniform radiation and homogeneous density of that body. Later, S. P. Langley, with experimental data derived from the direct radiation of the Sun. reduced this age to eighteen million years.

This theory immediately supplanted that of the falling meteors. which more serious reflection demonstrated could account only for the slight increase in the solar heat as compared with the energy of shrinkage.

Lord Kelvin, in 1862, returned to the subject, favoring a theory like that of Helmholtz', concluding that "we may accept as the lowest estimate for the Suns' initial heat 10,000,000 times a year's supply at the present rate, but 50,000,000 or 100,000,000 as possible in consequence of the Sun's greater density in his central parts." "As for the future, . . . inhabitants of the Earth cannot continue to enjoy the light and heat essential to their life for many million years longer unless sources now unknown to us are prepared in the great storehouse of creation." Studies of the Sun's heat were continued by Lord Kelvin, and in his theory he incorporated a discovery made in 1870 by J. Homer Lane, an American, which paradoxically demonstrated that within certain limits the more heat a gaseous body loses by radiation the hotter it will become.

This theory of Helmholtz', as modified by Kelvin, encountered a serious rival in 1882 when Sir William Siemens proposed that a rotating Sun hurled by centrifugal action at the equator enormous quantities of gas into space, which returned to it again at the poles, somewhat after the manner of a regenerative furnace. Helmholtz' theory was modified in 1899 by Professor T. J. J. See, who abandoned the German scientist's hypothesis of homogeneous density for the Sun and applied Lane's law, investigating minutely the more complex case of central condensation. As the result of his study the probable age of the Sun was extended from twenty-two million to about thirty-two million years.

All of these researches came before the discovery of radium, and when the extraordinary properties of this new substance were known it was stated that a bare fraction of a per cent. of radium present in the Sun would account for and make good the heat that is annually lost by radiation. Should this hypothesis hold good, an entirely new aspect is given to the problem of solar heat and to the heat of the Earth. This innovation, advanced by members of the younger school of physicists, all of whom had prosecuted with vigor researches in radioactivity, did not appeal to Lord Kelvin, who maintained in 1906 that the gravitation theory was still sufficient to account for the Sun's heat. Recently, evidence has been produced of the presence of radium in the Sun, and for some years past the presence of helium in the Sun has been well known. Indeed it was thus first discovered.

Sir George H. Darwin, in discussing the effect of these recent discoveries on solar age, says: "Knowing, as we now do, that an atom of matter is capable of containing an enormous store of energy

in itself, I think we have no right to assume that the Sun is incapable of liberating atomic energy to a degree at least comparable with that which it would do if made of radium. Accordingly, I see no reason for doubting the possibility of augmenting the estimate of solar heat, as derived from the theory of gravitation, by some such factor as ten or twenty.

"It is obvious, therefore, that while the contraction theory explains the origin of a vast amount of the Sun's heat, yet there are other sources of internal energy which recent discoveries plainly indicate are of great importance, so that the scientist at this stage is unable to declare positively the age of the Sun or to make any accurate estimate as to the probable duration of the time through which it will afford light and heat to the Earth and the other planets. Nevertheless, it seems assured that millions of years hence, how many cannot even roughly be determined, the Sun will be reduced from a ball of glowing vapor to a gigantic black cinder rushing through space. Unwarmed by any central luminary, its crust will be washed by oceans of air liquefied by a cold too intense for any living creature to endure.

The light of the Sun is obviously more intense than any other luminant known to man. If compared with the full Moon, 600,000 times as much light is received from the Sun. Expressed in another way, the Sun gives over 60,000 times as much illumination as a standard candle at a distance of one yard. But not all of the light and heat which is radiated from the Sun comes to the Earth. Professor Langley, in his experiments at Mt. Whitney in 1881, found that a clear atmosphere would cut off 40 per cent. of the rays coming perpendicularly to the Earth's surface. Gases in the atmosphere, such as carbon dioxide, cut off even a greater amount, and the general absorption is greater at the violet end than at the red. It is for this reason that high altitudes and a clear atmosphere are essential for solar investigation; and for this reason, too, that the setting Sun appears red, the bluish rays being absorbed in traversing a greater amount of terrestrial atmosphere than when the Sun is high in the sky.

The temperature of the Sun can be estimated from its brilliancy and from spectroscopic and bolometric studies. It is a common experience that a filament of an incandescent lamp emits more light and glows more brightly when the amount of current is increased. At first the filament is red, but as more current is permitted to flow it becomes yellow, and finally a brilliant white. This is marked by an increase in temperature; and secondly, the temperature depends upon the brilliancy of the glow. The same analogy holds good in the case of the Sun and the stars. If the wave length of the radiation is known, and the color which emits the greatest amount of heat

in the spectrum—and this can be measured by the bolometer by a simple law—it is possible to calculate the absolute temperature of a star. Then by deducting 270° from the result its temperature in the ordinary Centigrade degrees is obtained. Thus in the case of the Sun the maximum heat radiation occurs in the greenish-yellow light, which gives a temperature for the rotating disk of the Sun of about 5,000° C., or 9,000° F. The atmospheric absorption already referred to serves to cut down the intensity of the radiation, so that, taking this and other amounts into consideration, the temperature of the Sun's disk can be estimated at about 6,200° C.

Similar investigation in the case of Sirius and Vega, which are white, or younger stars, give a temperature about 1,000° C. higher than that of the Sun, while the red star, Betelgeux, which is a declining star, older than the Sun, has a temperature some 2,500° C. less. The temperature of the Sun furnishes different results, depending on the manner in which the problem is attacked. Arrhenius, in his work on "Worlds in the Making," summarizes recent work, and states that: "From the intensity of the radiation, Christiansen, and afterward Warburg, calculated a temperature of about 6,000° C. Wilson and Gray found for the center of the Sun 6,200°, which they afterward corrected into 8,000°." Owing to the absorption of light by the terrestrial and the solar atmospheres, too low values are always found. That applies to a still greater extent to any estimate based upon the determination of that wave length for which the heat emission from the solar spectrum is maximum. Le Chatelier compared the intensity of sunlight filtered through red glass with the intensities of light from several terrestrial sources of fairly well-known temperatures treated in the same way. These estimates yielded to him a solar temperature of 7,600° C. Most scientists accept an absolute temperature of 6,500°, corresponding with about 6,200 C. That is what is known as the "effective temperature" of the Sun.

If the solar rays were not partially absorbed this temperature would correspond with that of the clouds of the photosphere. Since red light is little absorbed, comparatively, Le Chatelier's value of 7,600° C., and the almost equal valuation of Wilson and Gray of 8,000° C., should represent approximately the average temperature of the outer portions of the clouds of the photosphere. The higher temperature of the faculæ is evident from their greater light intensity, which, however, may be partly due to their greater height. Carrington and Hodgson saw, on September 1, 1859, two faculæ break out from the edge of a sun-spot. Their splendor was five or six times greater than that of the surrounding parts of the photosphere. That would correspond with a temperature of about 10,000 or 12,000° C. The deeper parts of the Sun which broke out on these

occasions evidently have a higher temperature, and this is not unnatural, since the Sun is losing heat by radiation from its outer portions.

At all events, the Earth receives a large amount of energy in the form of light and heat which amounts to three horsepower for every square yard of space perpendicular to the Sun's rays; and while this really is not available for mechanical purposes, yet solar engines have been constructed in which this energy has been transformed into power. While the energy of the Sun is not, generally speaking, available for mechanical purposes, yet indirectly the heat received by the Earth has made possible plant and animal life, on which depends the source of all energy.

The transmission of the Sun's heat to the Earth is one of the important problems of present-day physics and meteorology, inasmuch as the amount of radiation or heat emitted by the Sun, spoken of by physicists as the "solar constant" and the relation of this radiation to terrestrial temperature, as well as the study of the radiation of different parts of the Sun's disk, are all topics of fundamental importance. The solar constant is measured outside of the Earth's atmosphere at mean solar distance, and the intensity of radiation is employed for a unit, which, when fully absorbed for one minute over a square centimeter of area placed at right angles to the ray, would produce sufficient heat to raise the temperature of a gram of water 1° C.

If once the original quantity and kind of heat emitted by the Sun be known, its effect on the constituents of the atmosphere on its journey to the Earth, how much of it reaches the soil, how through the change of the atmosphere it maintains the surface temperature of our globe, and finally, how in diminished quantity, or altered kind, it is returned to outer space, it would be possible to predict nearly all of the phenomena of the weather. Thus it has been known that when there is a small decrease in the solar radiation there follows a marked and general decline in temperature. So that, knowing the variation of radiation, it should be possible to predict changes in climate.

These data are secured by measuring the total intensity of the radiation, as it arrives at the Earth's surface, with the pyrheliometer, or thermometer with blackened bulb, carefully protected from all other influences except the direct rays of the Sun; and in the second place by measuring the heat or energy in different parts of the solar spectrum with the spectro-bolometer. The absorption of the atmosphere nearer the Earth for different areas requires measurements to be made at several stations, for at Washington, near the sea-level, the intensity of radiation actually observed is only about three-fourths as great as that observed in the clear atmosphere of Mount Wilson,

at a height of 6,000 feet. Recent observations made at Mount Wilson and Washington by Mr. Abbot, of the Astrophysical Laboratory of the Smithsonian Institution, indicate that heat sent out to the Earth from the Sun in the course of a year is capable of melting an ice shell 114 feet thick over the whole surface of the Earth. The solar radiation is not a constant quantity, but varies with the decrease in solar distance, the changes occurring from month to month and from year to year. The variation is due to the changes in the source of radiation rather than to the effects of our atmosphere or external causes.

The distance and position of the Sun as regards the other members of the Solar System have been considered in a previous chapter. It is known that its apparent diameter is 32′ 4″, which corresponds with 866,500 miles, or 109 1/2 times the diameter of the Earth. This would give it an area 11,950 times that of the Earth and a volume 1,306,500 times greater. The actual mass of the Sun is 332,000 times that of the Earth, but its average density is only about a quarter as great, so that the Sun, which has a density of 1.41 as compared with water, is four times as large as it would have to be if its density were the same as that of the Earth. Taking into consideration this lightness as well as the high temperatures prevailing in the Sun, one is forced to the conclusion that the body of the Sun must be in a gaseous state. The conditions under which the gases are found must be quite different from those with which we are acquainted on the Earth. Gravity at the surface of the Sun exceeds by more than twenty-seven times gravity on the Earth.

The motion of the Sun as regards the other stars in the heavens has been treated elsewhere, but it is proper here to refer to its rotation on its axis from west to east, which takes place in a period of about 25 days and is apparent from the motion of the sun-spots, tho it can also be detected by directing a spectroscope toward the edges of the limb and noting by Doppler's principle how one side is approaching the observer and the other is retreating. The time of rotation is not the same for all parts of the disk, but depends upon the position of the spots selected. Those nearest the equator show the most rapid rotation.

CHAPTER XI

MERCURY

Ancient records make no mention of the discovery of Mercury, yet the existence of the planet was surely known even in the days of Nineveh, when a chief astronomer directly refers to the planet in a report which he made to King Assurbanipal of Assyria. The planet is occasionally mentioned in early and medieval astronomical literature. It is stated that Copernicus regretted that he had never been able to observe it properly in the high altitude of Frauenburg.

That the planet should have been overlooked by the ancients is not strange when it is considered that it is never visible in the higher altitudes except occasionally near the horizon, just after sunset or before sunrise. In the clear sky over an eastern desert the primeval astronomer doubtless saw the bright star in that part of the horizon where the setting Sun was still shedding its beams. Its luster diminishes as the planet draws near the horizon at sunset, until finally it sets so soon after the Sun that it is invisible. Years may elapse before a similar opportunity is afforded.

If a similar phenomenon took place at sunrise, the primitive astronomer might have inferred that Venus and Mercury were identical, especially as a long series of observations would establish the fact that one of these bodies was never seen until the other had disappeared. Accordingly some of the ancient astronomers assumed that there was but one morning and evening star. But as records accumulated it was recognized that there were two bodies which might serve as morning and evening stars. A certain regularity in the recurrence of each planet was noted, and it was possible to make predictions of accuracy as to the time when either could be seen after sunset or before sunrise.

While by the time of Plato it was known that Venus and Mercury performed their revolution in approximately the same time, it was recognized that Mercury's period was different and more rapid than that of other planets. An older tradition, attributed to the Egyptians, stated that both planets revolved around the Sun. Ptolemy states that they could be regarded as oscillating to and fro on each side of the Sun. That the ancient astronomers might well have been confused by the appearance of Mercury as morning and evening star

follows from a considedation of the planet's position and motion relatively to the Sun and the Earth. The consideration, moreover, applies to Venus as well.

Quoting C. G. Dolmage's "Astronomy of To-day," "when furthest from us Mercury is at the other side of the Sun, and cannot then be seen owing to the blaze of light. As it continues its journey it passes to the left of the Sun, and is then sufficiently away from the glare to be plainly seen. It next draws in again toward the Sun, and is once more lost to view in the blaze at the time of its passing nearest to us. Then it gradually comes out to view on the right hand, separates from the Sun up to a certain distance as before, and again recedes beyond the Sun, and is for the time being once more lost to view.

"To these various positions technical names are given. When the inferior planet is on the far side of the Sun from us it is said to be in 'Superior Conjunction.' When it has drawn as far as it can to the left hand, and is then as east as possible of the Sun, it is said to be at its 'Greatest Eastern Elongation.' Again when it is passing nearest to us it is said to be in 'Inferior Conjunction'; and finally, when it has drawn as far as it can to the right hand, it is spoken of as being at its 'Greatest Western Elongation.'"

The continual variation in the distance of the inferior planets, Venus and Mercury, from the Earth, during their revolution around the Sun, will of course be productive of great alterations in apparent size, which no doubt also had its effect in bewildering the ancients. At superior conjunction, being then farthest away, Mercury ought to show the smallest disk; while at inferior conjunction, being the nearest, it should appear much larger. When at greatest elongation, whether eastern or western, it should naturally present an appearance midway in size between the two.

From these considerations it would seem that the best time for studying the surface of Venus or Mercury is at inferior conjunction, or when the planet is nearest to the Earth. But that this is not the case will at once appear if it is considered that the Sun's light is then falling upon the side most distant, leaving the proximate side unillumined. In superior conjunction, on the other hand, the light falls full upon the side of the planet facing the Earth; but the disk is then so small and the view besides is so dazzled by the proximity of the Sun that observations are of little avail. In the elongations, however, the sunlight comes from the side, and so we see one-half of the planet lit up; the right half at eastern elongation and the left half at western elongation. Piecing together the results given at these more favorable views, it is possible, bit by bit, to gather some small knowledge concerning the surface of Mercury or Venus.

Consequently it will be seen that the inferior planets show various phases comparable with the waxing and waning of the Moon in its

monthly round. Superior conjunction is, in fact, similar to full Moon, and inferior conjunction to new Moon; while the eastern and western elongations may be compared respectively with the Moon's first and last quarters. When these phases were first seen by the early telescopic observers, the Copernican theory was felt to be immeasurably strengthened; for it had been pointed out that if this system were correct, the planets Venus and Mercury, were it possible to see them more distinctly, would of necessity present phases when viewed from the Earth.

The apparent swing of an inferior planet from side to side of the Sun, at one time on the east side, then passing into and lost in the Sun's rays, to appear once more on the west side, is the explanation of what is meant when one speaks of an "evening star" or a "morning star." Mercury or Venus is called an "evening star" when it is at its eastern elongation—that is to say, on the left hand of the Sun; for being then on the eastern side, it will set after the Sun sets, as both sink in their turn below the western horizon at the close of day. Similarly, when either planet is at its western elongation—that is to say, to the right hand of the Sun—it will precede him, and so will rise above the eastern horizon before the Sun, receiving therefore the designation of "morning star."

Mercury's motions were early studied. With the planet was associated the first of the remarkable astronomical predictions that now have become almost commonplace, so carefully are they worked out by astronomers. Kepler, from his studies of the motions of the planet, was the first to realize that if the orbit of Mercury, which, as has been seen, lies within that of the Earth and thus nearer the Sun, were exactly circular and in the plane of the ecliptic, a transit of Mercury across the Sun's disk would occur once in each synodical revolution, or period between two successive conjunctions of the planet with the Sun as seen from the Earth, the epoch of the transit could be calculated very easily. But Mercury's orbit is inclined 7 degrees to the ecliptic and is very eccentric, for which reason his calculations were only approximately correct.

It was in 1627 that Kepler predicted transits of both Mercury and Venus across the Sun, and assigned the date of November 7th for the former. Gassendi, to whom was entrusted the task of proving Kepler's prophecy, began his observation on the 5th of November, watching the image of the Sun formed by a lens on a white screen from light admitted through a hole in a dark room. But Kepler was not in error by as much as that. Only five hours after the time assigned did the transit actually begin. Thus was commenced a series of observations of the time when Mercury crosses the great central luminary of this system. These transits are by no means rare, for thirteen of them were observed in the nineteenth century. They

afford opportunity for observation which enables the movements of the planet to be calculated with accuracy.

After the transits of 1661 and 1677 La Hire constructed new tables of Mercury and predicted a transit on May 5, 1707. The calculation was in error by nearly a day. After the transit of May, 1753, had been observed several hours later than La Hire's and as much earlier than Halley's prediction, Lalande constructed new tables, and predicted the transit of 1786, which actually took place fifty-three minutes later than the time pronounced by Lalande and about as much earlier than the time computed by Halley's tables. Lalande then corrected his tables and predicted the transits of 1789, 1799 and 1802 with a fair approach to accuracy. The tables compiled by Lindenau 1813 still left much to be desired.

The problem of Mercury's motion was in this condition when it was attacked by Leverrier, who was under no illusion in regard to its difficulty. Leverrier did not succeed in overcoming the difficulty until 1859. As a result of his work, supplemented by that of later investigators, astronomers are not in possession of at least fairly accurate information on the subject of the planet's orbital phenomena. It is known, for example, that Mercury is the swiftest in its movements of all the planets. With the exception of some of the satellites, it has an orbit that departs most from the circular form—in other words, an orbit marked not only by the greatest eccentricity, but also by the greatest inclination of all planetary orbits to the ecliptic. This eccentricity of the orbit is such that the Sun is seven and one-half million miles out of its center, while the actual distance of the planet from the Sun ranges from about twenty-nine million miles to forty-three million, or a mean distance of about thirty-six millions of miles. The velocity varies from thirty-five miles a second, when the planet is at perihelion or nearest the Sun at the pointed end of its oval course, to about twenty-three miles a second at aphelion.

To explain the perturbations in Mercury's motion, Abbé Moreux has recently advanced the following hypothesis: "The Sun is unquestionably surrounded by matter which gives rise to the observed phenomena of the corona. Photographs made during the eclipse of 1905 showed an outer corona extending to a hitherto unsuspected distance from the Sun. This outer corona is ellipsoidal and its major axis is very nearly coincident with that of the zodiacal light. This region, then, is filled with a resisting medium, composed of matter which is gradually falling in toward the Sun. The mechanism of this fall, or contraction, is very complex, and as we have no idea of the density of the matter, it is difficult to calculate its changes in form.

"The resistance which the medium opposes to a moving body is

likewise difficult to estimate, but we know from the observed acceleration of comets that this resistance is by no means negligible. At the epochs of maximum coronal development this resisting medium may easily extend to the orbit of Mercury. Hence that planet in its revolution around the Sun must traverse masses of rarefied gas and swarms of minute particles by which its course is modified. We are far from knowing the quantitative effect of the resisting medium, and much study of the corona will be required to complete the solution of this interesting problem."

Because of the lack of surface markings the rotation periods are very uncertain. Recently Professor McHarg, in France, has deduced a rotation of 24 h. 8 m. G. Schiaparelli has put forward the view that both Venus and Mercury rotate in a time equal to the individual period of revolution around the Sun, and thus always turn the same face toward the Sun. Such a motion, which is analogous to that of the Moon around the Earth, could be easily explained as the result of tidal action at some past time when the planets were, to a great extent, fluid. This may be true, as Mercury is one of the planets which has no Moon and consequently will be influenced directly and solely by the Sun in so far as tidal phenomena are concerned. These tidal effects must be especially severe on account of the proximity of Mercury to the Sun.

Because of this lack of a satellite the mass of the planet is very difficult to determine. At various times Laplace, Encke and Leverrier have given values from 1/9 to 1/30 of the Earth's mass. The first convenient opportunity of placing this planet in a gravitational balance and of determining its mass was presented in August, 1835, when Encke's comet in the course of its eccentric path through the solar system penetrated within the orbit of Mercury at its perihelion. The attractive power of the planet produced only a slight deviation from the regular course of the comet, sufficient, however, to show that the value previously assumed for Mercury's mass was nearly twice too large. At the same time the calculations made from these data have not removed the uncertainty that still prevails upon this point; Simon Newcomb decided on a value of about 1/21 that of the earth, while William Harkness made it 1/25.

Beyond its motion comparatively little is known of Mercury. The spectroscope seems to indicate that the atmosphere of Mercury contains water vapor just as does the Earth. But the studies of Professor Lowell at Flagstaff, Arizona, do not show any signs of clouds or obscurations, and there are no indications of any atmospheric envelope. In fact, the surface of Mercury has been termed colorless, "a geography in black and white."

The first student of the surface of Mercury was Johann Hieronymus

Schröter (1745-1816), who, as will be seen, was a pioneer in the study of the topography of the Moon. In April 1792, Schröter concluded from the gradual degradation of light on its brightly illuminated disk that Mercury possessed a tolerably dense atmosphere. During the transit of May 7, 1799, he was struck with the appearance of a ring of softened luminosity circling the planet to a height of 3″ and about a quarter of its own diameter.

Referring to this ring of softened luminosity, Agnes Clerke writes in her "History of Astronomy": "Altho a 'mere thought' in texture, it remained persistently visible both with the seven-foot and the thirteen-foot reflectors, armed with powers up to 288. A similar appendage had been noticed by De Plantade at Montpellier, November 11, 1736, and again in 1786 and 1789 by Prosperin and Flaugergues; but Herschel, on November 9, 1802, saw the preceding limb of the planet projected on the Sun cut the luminous solar clouds with the most perfect sharpness. The presence, however, of a 'halo' was unmistakable in 1832, when Professor Moll, of Utrecht, described it as a 'nebulous ring of a darker tinge approaching to the violet color.' Again to Sir William Huggens and Stone, on November 5, 1868, it showed as lucid and most distinct.

"No change in the color of the glasses used, or the powers applied, could get rid of it, and it lasted throughout the transit. It was next seen by Christie and Dunkin at Greenwich, May 6, 1878, and with much precision of detail by Trouvelot at Cambridge, Mass. Professor Holden, on the other hand, noted at Hastings-on-Hudson the total absence of all anomalous appearances. Nor could any vestige of them be seen by Barnard at Lick on November 10, 1894. Various effects of irradiation and diffraction were, however, observed by Lowell and W. H. Pickering at Flagstaff; and Davidson was favored at San Francisco with glimpses of the historic aureola, a well as of a central whitish spot which often accompanies it. That both are somehow of optical production can scarcely be doubted."

The planet's physical condition presents many problems and the spectroscope affords little information as to its constitution. As it shines only by reflected light from the Sun, its spectrum is but a fine echo of the Fraunhofer lines. An atmosphere like that of the Earth was suspected, however, by H. C. Vogel in 1871 from his spectroscopic studies, tho on the very slightest grounds.

Later observations made at the Potsdam Observatory by Müller confirm this conclusion and demonstrate that Mercury has a rough rind of dusty rock, which absorbs all but 17 per cent. of the direct light radiated upon it by the near-by Sun. This would seem to show the utter absence of any appreciable Mercurian atmosphere. The probable lack of atmosphere is also shown by the circumstance that

when Mercury is just about to transit the face of the Sun, no ring of diffused light is seen to encircle its disk, as would be the case if it possessed an atmosphere.

According to the Belgian astronomer, Stroobant, the linear diameter of Mercury is expressed as a fraction of the Earth's is 0.350 instead of the previously accepted 0.373, the radius 2,232 kilometers (1,386.7 miles), and the volume, compared with that of the Earth, 0.420.

CHAPTER XII

VENUS

For all time Venus has been known as evening and morning star. By the ancients it was supposed to be two separate bodies which were named Phosphorous (Lucifer) or Morning Star and Hesperus (Vesper) or Evening Star. For Pythagoras in the sixth century B.C. is claimed the honor of discovering the identity of the two stars, but it was probable that he restated the views of Eastern astronomers.

As the most brilliant star of the heavens, Venus is certainly the one that has always been most observed. Glittering in the sky like a clear diamond, its pure white light, which, on a night when there is no Moon, is strong enough to cast a shadow, naturally would impress all whose lives are spent out of doors. Hence Venus has always figured in literature as the "Shepherds' Star." Homer speaks of the planet as Kallistos—the "Beautiful," and as a type of beauty its worship figures in all mythologies. At a time when the planets were personified as gods and goddesses it is easy to understand why this star was selected to typify Love.

Not only on account of its splendor in the evening sky, but for other phenomena, Venus is familiar in history and literature. The historian Varro (116-28 B.C.) states that "Æneas on his voyage from Troy to Italy saw this planet constantly above the horizon," and the same historian is quoted by St. Augustine as speaking of a change in the color and brilliancy of Venus. In 1716 the visibility of Venus in full daylight was hailed as a marvel by the people of London, and in 1750 its appearance at noon aroused general astonishment in Paris. Again, in 1797, when Napoleon returned to Paris from his conquest of Italy he found the attention of the populace divided between his reappearance and a similar striking midday phenomenon. In fact, Bonaparte always associated this star with his fortunes, and one evening while engaged in viewing the starry heavens, pointing to the planet, said to Prince Talleyrand, "Do you see? That is my star! So long as it shines I will have no doubt of success."

In more recent times many brilliant appearances of the planet have been observed, the interval between periods of greatest visibility amounting to eight years. At one of these, in April, 1905, at Cherbourg, Venus appeared as a bright meteor of appreciable size and full form, an effect which was due partly to the formation of a halo.

According to the Ptolemaic theory, Venus was always between the Earth and the supposed orbit of the Sun. Hence it was possible that, at the most, but half of its illuminated surface could be visible to the Earth. When Galileo, with his telescope, in 1610, made the striking discovery that Venus appeared in various phases just as the Moon, exhibiting the gibbous as well as the crescent phase, it was strong and almost the last argument necessary to establish beyond question the Copernican theory that the planets revolve around the Sun. Were Venus as large as Jupiter, for example, the phases would readily be discerned by the unaided eye. Indeed, Sir Robert Ball has wondered what would have been the effect on the history of astronomy had Venus been of the size of Jupiter so that its crescent form could have been seen without a telescope. Then the elementary truth would have been apparent that Venus was a dark body revolving around the Sun. The analogy between it and our Earth would have been at once perceived and the theory of Corpernicus long since might have been established.

The mean distance of Venus from the Sun is 67,200,000 miles. With the exception of the Moon and an occasional comet no other heavenly body comes so near the Earth at any time. The orbit is marked by the smallest eccentricity in the planetary system, and is therefore more nearly circular than that of any other planet. The planet's greatest and least distances from the Sun vary from the mean only by about 470,000 miles each way.

Venus is the nearest planet to the Earth, as there is only 26,000,000 miles between the orbits of the two at inferior conjunction or their nearest approach, yet Venus is not as well known as Mars, since when Venus passes nearest the Earth it is then between it and the Sun, so that the hemisphere which is illuminated is not visible to the Earth.

The appearance of Venus in the sky as the evening and the morning star was no less impressive to the ancients than the beautiful character of the star itself. It is as familiar now as it was to the shepherds of old that when Venus disengages itself in the evening from the rays of the Setting Sun it departs from the Sun a little more every night, increasing its brilliancy until a certain distance in the east is reached, appearing, like the Moon, to travel toward the left of the observer. At the end of a few months it has removed itself from the Sun to an angular distance that may amount to as much as 48°, at which time the planet sets more than three hours after the Sun. After shining for some months, little by little the planet begins to return toward the Sun, receding more and more from the Earth, then passing behind the central luminary and thus ceasing to be the evening star.

After an interval a new star is seen in the early morning to precede the rising of the Sun, advancing by imperceptible degrees every day,

and eclipsing likewise all the bodies of the heavens by its dazzling light. At this time it proceeds towards the west, that is, toward the observer's right hand, and we have now the "morning star." After having preceded the rising of the Sun by three hours, Venus resumes its course anew toward the Sun and again is lost in the glare of day. It is then passing between the Sun and the Earth and is at its greatest proximity to the Earth. Sometimes it passes just in front of the Sun, as it did in 1874 and 1882, which phenomenon is known as a transit. As it happens but twice in a century a transit is an occurrence of considerable importance to astronomers.

These transits are valuable for the easy determination of the position of the planet, for the investigation of its atmosphere and for the determination of the solar parallax by comparing the amount of apparent displacement in the planet's path across the solar disk when the transit is observed at widely separated stations on the Earth's surface. These transits occur in June and December, taking place in cycles whose intervals are 8, 105.5, 8, 121.5 years. They have occurred on the following dates: Dec. 7, 1631; Dec. 24, 1639; June 5, 1761; June 3, 1769; Dec. 9, 1874; Dec. 6, 1882; and will occur again on June 8, 2004, and June 6, 2012.

The first observed transit, namely, that of 1639, was watched in England by two persons, Jeremiah Horrocks and a friend, William Crabtree, whom Horrocks had forewarned of its occurrence. That the transit was observed at all was due entirely to the remarkable ability of Horrocks. According to the calculations of Kepler, no transit could take place that year (1639), as the planet would just pass clear of the lower edge of the Sun. Horrocks, however, worked the question out for himself, and came to the conclusion that the planet would actually traverse the lower portion of the Sun's disk. The event proved him to be right. Horrocks, who was said to have been a veritable prodigy of astronomical skill, unfortunately died about two years after this celebrated transit, in his twenty-second year.

The transits of Venus next observed in 1761 and 1769 were taken advantage of by Edmund Halley to suggest a means of ascertaining the distance of the Sun. The idea had originated in rather vague form with Kepler, but was suggested more definitely by James Gregory in 1663. After Halley had observed the transits of Mercury in 1677 he realized the advantages of the method and published several papers urging preparations for observing the transit.

"He pointed out," says Berry, treating of this point in his "Short History of Astronomy," "that the desired result could be deduced from a comparison of the durations of the transit of Venus as seen from different stations of the Earth, *i.e.*, of the intervals between the first

appearance of Venus on the Sun's disk and the final disappearance, as seen at two or more different stations. He estimated, moreover, that this interval of time, which would be several hours in length, could be measured with an error of only about two seconds, and that in consequence the method might be relied upon to give the distance of the Sun to about 1/500 part of its true value. As the current estimates of the Sun's distance differed among one another by 20 or 30 per cent., the new method, expounded with Halley's customary lucidity and enthusiasm, not unnaturally stimulated astronomers to take great trouble to carry out Halley's recommendations. The results, however, were by no means equal to Halley's expectations."

Immense trouble was taken by governments, academies and private persons in arranging for the observation of the transits of 1761 and 1769. For the former, observing parties were sent as far as to Tobolsk, St. Helena, the Cape of Good Hope and India, while observations were also made by astronomers at Greenwich, Paris, Vienna, Upsala and elsewhere in Europe. The next following transit was observed on an even larger scale, the stations selected ranging from Siberia to California, from the Varanger Fjord to Otaheite (where no less famous a person that Captain Cook was placed), and from Hudson's Bay to Madras.

The expeditions organized on this occasion by the American Philosophical Society may be regarded as the first of the contributions made by America to the science which has since owed so much to her; while the Empress Catherine of Russia bore witness to the newly acquired civilization of her country by establishing a number of observing station on the soil of her Empire.

A variety of causes prevented the movements of contact between disks of Venus and the Sun from being observed with the precision that had been hoped. The values of the parallax of the Sun deduced from the earlier of the two transits ranged between 8″ and 10″; while those obtained in 1769, tho much more consistent, still varied between 8″ and 9″, corresponding with a variation of about 10,000,000 miles in the distance of the Sun. The whole set of observations was subsequently very elaborately discussed in 1822-4 and again in 1835 by Johann Franz Encke, who deduced a parallax of 8″.571, corresponding with a distance of 95,370,000 miles, a number which long remained classical. The uncertainty of the data is shown by the fact that other equally competent astronomers have deduced from the observations of 1769 parallaxes of 8″.8 and 8″.9.

The transits of Venus in 1874 and 1882 were memorable as the first in which photographic methods and the heliometer were applied, in addition to the older methods of time observation to measure the occasion of contact. The older methods left unavailable the remainder

of the transit, but the heliometer made it possible to ascertain the planet's apparent position upon the Sun's disk at any time with great precision. In the transit of 1874 the most elaborate photographic measures ever undertaken until this time, were carried out in the United States where the conditions were most favorable.

A continuous succession of photographs was made as the planet traveled across the Sun's disk, and various systems of reference enabled its position to be identified with great accuracy at any part of the transit. Yet results were hardly more valuable than those obtained by the other methods. Hence in 1882 the American observers modified their apparatus considerably from previous practice by employing the photographic plate and using the heliostat to reflect the Sun's rays through a telescope lens 5 inches in diameter and of 40-foot focal length. Doubtless better results could be obtained to-day with modern solar photographic equipment and dry plates. No great advances were recorded as the result of the numerous expeditions during these two transits.

Elaborate expeditions were equipped, particularly for the second of the two transits, and the observations, which were voluminous, were thoroly and systematically discussed. The results were a somewhat larger value of the solar parallax, amounting to 8″.857, or rather less than 93,000,000 miles, as obtained by Newcomb after combining the heliometer with photographic measurements. As all measures of this kind seem to be affected by some constant systematic error, it is the concensus of opinion among astronomers that other methods are more to be trusted in determining the solar parallax than those based on the transits of Venus.

The great brilliancy of Venus is due to its relatively small distance from the Sun and the Earth and to its great reflecting power. The albedo of Venus, or the ratio of reflected to incident light, is 0.76. In other words, the planet reflects three-fourths of the light that falls upon it from the Sun, a proportion which is little exceeded by freshly fallen snow. This indicates that Venus is surrounded by a dense and cloudy atmosphere. Similar indications are given by the spectroscope, pointing to the existence of an atmosphere containing water vapor and generally similar to our own, but denser.

This atmosphere of Venus, owing to its great refractive power, sometimes appears as a luminous ring in transits of the planet. From observations made at the transit of 1882 it has been computed that the density of the atmosphere of Venus is 1.8 that of the Earth's atmosphere, which produces a refractive displacement of 33″. According to Maedler's calculations, the atmosphere of Venus is 1.7 times as dense as that of the Earth.

Many astronomers believe therefore that Venus is surrounded by a

dense atmosphere into which the Sun's rays do not penetrate to a depth sufficient to cause much loss by absorption—probably because they are reflected by opaque clouds. From this it would follow that the markings which have been observed on the disk of Venus through the telescope for centuries may be purely atmospheric. As the displacement of the surface markings of a planet when viewed through a telescope furnish the basis for estimates of the period of rotation, it may be that calculations so made are without justification.

These markings of Venus are altogether different from those of any other planet. They are faint, indistinct and apparently variable, for the drawings of Venus made by different observers before the advent of photography are very unlike. The first astronomer to observe any markings on Venus was Domenico Cassini, who discovered a bright spot in 1666. In the following year he discovered a second spot, from which he deduced a period of rotation of about 24 hours, an estimate which was reduced to 23 hours and 22 minutes in Jacques Cassini's revision of his father's work. On the other hand, Bianchini, who studied the planet in 1726-1727, deduced from his observations a period of rotation equal to 24 days and 8 hours.

Thus began the long and violent controversy in regard to the rotation of Venus. From more than 10,000 observations made between 1830 and 1841 De Vico computed a mean value of 23 hours, 21 minutes and 23.93 seconds for the period of rotation of Venus. This value, furthermore, agrees very closely with the period of 23 hours and 21 minutes deduced by Schröter from observations of the deformation of the horns of Venus (1788-1793), and it has consequently been adopted in most treatises on astronomy. But in 1890, however, belief in the short period was shaken by Schiaparelli's discoveries. Before this Schiaparelli had made the surprising announcement that the period of rotation of Mercury was equal to the period of its revolution about the Sun, and he now asserted that the same law governed the motions of Venus, a statement based on observations made in the winter of 1877-78, which showed that the bright spots then visible never varied their positions with respect to the terminator, or boundary line between the planet and its shadow. Observations made in 1895 gave additional support to the view that Venus rotates on her axis in the period of her revolution about the Sun (225 days), and consequently always turns the same hemisphere toward the Sun, just as the Moon always presents the same face to the Earth.

This theory, which on its announcement rested solely on Schiaparelli's authority, soon obtained strong independent support. It has apparently been completely confirmed by the observations made by Lowell at Flagstaff, Arizona, in 1895-6. Lowell saw markings that have been seen by no other astronomer, before or since, but the

most surprising thing about his discoveries is that he saw no spots, but only bands or lines bearing a superficial resemblance to the canals of Mars. The whole configuration remained unchanged for hours, which could not be the case if the period of rotation were only 24 hours. Furthermore, the markings remained fixed relatively to the terminator. Lowell denies the existence of clouds on Venus, altho he finds in certain phenomena of twilight evidence of the presence of a very dense atmosphere.

Many astronomers have refused to accept the conclusions of Schiaparelli, Perrotin and Lowell, and have adhered to the theory of a short period of rotation. Schiaparelli's first announcement was vigorously disputed, soon after its publication, by the French astronomer, Trouvelot. During his residence at Cambridge, Mass., from 1875 to 1882, Trouvelot pointed out seventeen changes in the markings which Schiaparelli regarded as fixed. Trouvelot regarded the bright spots on the limb of the planet as very high mountains, rising above the atmosphere.

The observed changes in the appearance of the horns of the crescent planet have also been ascribed to mountains. In the eighteenth century Schröter announced the discovery of several mountains on Venus. In 1789 the southern horn of the crescent appeared blunted and near it on the dark disk of the planet shone a bright peak, the height of which was estimated by Schröter, as 117,000 feet, or 22 miles. Trouvelot deduced from his own observations a period of rotation of about 24 hours. It is very remarkable that two such experienced and trustworthy observers as Schiaparelli and Trouvelot could be led to such widely differing results from their frequent observations of the same object during the same period. It may be regarded as certain that the problem of the rotation of Venus cannot be solved by observing markings, which is not surprising if they are purely atmospheric phenomena.

Sir William Herschel, who has justly been called the greatest observer of all time, doubted the reality of the markings of Venus and regarded them as atmospheric phenomena, but this view was not shared by any of his contemporaries. Beer and Maedler, who were also most excellent observers, studied Venus repeatedly in 1833 and later years, but they rarely, if ever, saw anything that deserved the name of a marking.

Attempts have been made to solve the interesting and difficult problem of the rotation of Venus with the aid of the spectroscope, but these attempts have also failed to give a positive result. The effort was first made by the Russian spectroscopist, Bjelopolsky, at the Pulkowa Observatory. The spectrophotographic measurements which were begun in 1900 indicated a short period of rotation. Al-

though Bjelopolsky did not regard the correctness of the result as assured, his authority led to the belief that the spectroscope had decided the question in favor of the short period. Then Lowell, who had deduced a period of 225 days from telescopic observations, sought confirmation for this value by the spectroscopic method. He first tested his new and delicate apparatus and method by applying them to Mars, and obtained for that planet a period of rotation of 25 hours and 35 minutes, which agrees fairly well with the known period, 24 hours and 37 minutes. For Venus, Lowell's spectrophotographs give a rotational velocity of from 5 to 8 meters (16.4 to 26.2 ft.) per second, which corresponds with a long period of rotation, tho one much shorter than 225 days, for which the equatorial velocity would be about 2 meters (6.56 ft.) per second.

Neither of the results obtained at Pulkowa and at Flagstaff has yet been confirmed elsewhere. The spectroscopic method is too difficult to be attempted except by particularly well equipped and favorably situated observatory. The theory of slow rotation receives powerful support from certain arguments advanced by the distinguished English astronomer, Sir George H. Darwin. The rotational velocity of every planet must be gradually diminished by tidal friction among its parts. In this way the period of the Moon's rotation has been made equal to the period of her rotation about the Earth, and the rotational periods of Mercury and Venus may have been similarly lengthened to equality with their periods of revolution about the Sun, which exerts a far greater tidal action upon these inferior planets than upon the Earth.

If Venus has already reached this stage, all the water on the planet must be accumulated in the form of ice on the dark and intensely cold hemisphere. Hence, as Antoniadi has pointed out, the presence of clouds and water vapor on the illuminated hemisphere casts grave doubt on the correctness of Schiaparelli's theory. The presence of clouds in the atmosphere of Venus is denied only by Lowell, who saw the peculiar canal-like markings distinctly whenever terrestrial atmospheric conditions permitted.

No trace of markings, by the way, was seen by Hansky and Stefanik, who studied the planet in the summer of 1907 at the Mont Blanc observatory, which is more elevated than Flagstaff, under very favorable atmospheric conditions, and deduced a period of rotation slightly less than 24 hours. So the problem of the rotation of Venus is still unsolved, altho a majority of astronomers appear to share the view of Schiaparelli and Lowell. The hope that it can be solved by observing markings has proven illusory, but there is good reason to believe that the spectroscope will ultimately furnish the solution.

Venus in size is almost identical with the Earth. Its diameter ex-

pressed in miles is 7,800, as compared with 7,920 for the Earth. Its circumference consequently amounts to 23,400 miles, as compared with 25,000 miles, that of the Earth. The period of revolution around the Sun is 225 days.

For many years observers have been looking for satellites of Venus. Fontana (1645), Cassini (1672 and 1686) and Montaigne (1761), among others, imagined that they had made such a discovery, but these have for many years been considered optical illusions.

CHAPTER XIII

THE EARTH

THE conception of the Earth formulated by the ancients assumed it to be a flat disk floating on water, which idea persisted in some form or other despite various phenomena clearly impossible of explanation upon such a hypothesis. After some more or less vague speculation on the shape of the Earth by Thales (640[?]546 B.C.[?]), a clear and rational idea was advanced by Pythagoras, who flourished in the sixth century B.C. and taught that the Earth, in common with the heavenly bodies, was a sphere and that it received no support at the center of the universe. The idea of the sphericity of the Earth was doubtless derived by analogy from the appearance of the Moon. The theory became an established part of Greek science and philosophy and consequently has continued to the present day, anticipating by some 2,000 years the acceptance of the belief in the Earth's rotation. In fact, the spherical form of the Earth figured prominently in Greek astronomy, and the division of the Earth into zones and the idea of poles was promulgated by the Alexandrian philosophers and even before their time. Indeed, not only did they realize the shape of the Earth, but also its size. Erathosthenes (276-195 or 196 B.C.), whom we have already mentioned in our chapter on pretelescopic work, made one of the first scientific measurements of the Earth, obtaining a result which must be considered the first good geodetic measurement. He found from the application of simple geometry that the angular distance of the Earth's surface between Alexandria and Syene must be 1/50 of the circumference of the Earth. Posidonius, who was born about the end of the life of Hipparchus, made a new measurement of the circumference of the Earth, much after the fashion of that of Eratosthenes, but reaching a value too small. One of the crucial arguments for the sphericity of the Earth is that when a ship sails away the hull first disappears from view while the masts are visible. This was first advanced by Pliny (23-79 A.D.).

From the Greeks and Romans to the Arabs may be a far journey, but little was done in the study of the Earth until the Arab astronomers at Bagdad, under the patronage of Caliph Al Mamun, made a series of measurements of a meridian of the Earth which agreed with that of Ptolemy. These measurements virtually sufficed until Wille-

brod Snell (1591-1626), a Dutch mathematician who had discovered the law of the refraction of light, made a series of measurements of the Earth's surface from which he computed the length of a degree of a meridian to be about 67 miles, an estimate subsequently corrected to about 69 miles by one of his pupils and differing but a few hundred feet from the value now accepted. A measurement by Richard Norwood (1590[?]-1675) of the distance from London to York, made in 1636, enabled a degree of latitude to be obtained with an error of less than half a mile, and finally Picard, in 1671, made a measurement of this quantity, which we have seen was sufficiently accurate to be used by Newton in computing the mass and motion of the Earth and in demonstrating his law of gravitation.

This outline shows that the spherical shape of the Earth was constantly held in mind by scientists for about 2,500 years. Other views of the Earth's shape also obtained. The idea of a flat Earth had to be vigorously opposed by arguments founded on experiment, observation and discovery. After the phenomenon of a disappearing ship, one of the most important of the arguments against the flatness of the Earth's surface was based on the different elevations of the Pole Star in the sky, depending upon the position of the observer. Now the Pole Star and the surrounding stars, tho they may be at different heights in the sky, form the same pattern wherever on the Earth's surface they are seen, thus showing that they are immensely distant and that lines from all points of the Earth's surface directed to the Pole Star would be parallel or have the same direction. As one travels north it is seen that the Pole Star rises higher and higher in the heavens or has a lesser angular distance from our zenith. If the Earth were flat this would not be the case, for an angular distance of 7½ degrees difference in the position of two stations 520 miles apart in a north-and-south line would mean that the star is only 3,450 miles distant, which is manifestly impossible. Furthermore, it is a well-known experience that in crossing the Atlantic from England to the United States the sun, by a watch, rises an hour later for every 600 miles we travel west. If the Earth were flat the Sun would rise at the same instant over its entire surface. To answer both these conditions—namely, the rising in the heavens of the Pole Star and the equal delays in the time of sunrise in traveling equal distances—a round globe is required.

Still the globular form of the Earth was not accepted generally until after the historic voyage of Christopher Columbus and that epoch of exploration and discovery which resulted in the circumnavigation of the Earth in 1519. After the demonstration of the sphericity of the Earth came the determination of its exact figure by the systematic measuring of arcs of meridians. When the results were mathematically examined the conclusion was reached that the Earth

was not a perfect sphere, but flattened at the ends, or in other words that it was an oblate spheroid. Newton in his Principai, published in 1687, showed from theoretical considerations that the Earth bulged out at the equatorial regions. On the other hand, in the following century (in 1745) the Cassinis, who were leading astronomers of France and deeply interested in the measurement of the Earth's surface, maintained that the Earth was contracted at the equator and bulged at the poles, or in other words was prolate, the difference in the two ideas being concisely expressed by Professor Moulton, who likens Newton's idea of the Earth's figure to an orange and that of the Cassinis to a lemon.

It is interesting that Newton's proof of the oblateness of the Earth anticipated the direct observations of the astronomer and geodesist. To-day it can be demonstrated in simple form by means of observations of the time of vibration of a pendulum, such as are carried on systematically by such scientific agencies as the United States Coast and Geodetic Survey.

It is possible to supply various mathematical proofs of the oblateness of the Earth in connection with its motions and with its relations to the Moon and to the solar system. But these hardly concern us in the present pages, and we may dismiss the matter with the assertion that the ellipticity of the Earth as determined by Harkness in 1891 amounts to 1/300, as compared with a value of 1/295 established in 1866 by Colonel Clarke, of the English Ordnance Survey, and accepted for many years as a standard, and 1/230, as was given by Newton for the ellipticity of a meridian section of this oblate spheroid. Clark's spheroid of 1866, which is generally adopted in geodetic and other computations, would give a radius at the equator of 3,963.307 miles and 3,949.871 miles at the poles, these figures having been slightly corrected in 1878 in the second place of decimals. The radius of the Earth is in many ways a fundamental measure, especially in astronomy, and for that reason its determination is a matter of no small importance. Thus observations made with a view of finding the distance of the Moon, when discussed and reduced, simply give us this distance in terms of the equatorial radius of the Earth, so that to determine the distance in miles we must know the number of miles in the Earth's radius.

As a consequence of the spheroidal shape of the Earth a degree of latitude, as well as of longitude, varies with the point at which it is measured. Thus at the equator one degree of latitude is equal to 68.704 miles, but at the pole a similar degree is equal to 69.407 miles. The difference in a degree measured on the parallel of latitude, which are small circles, is of course obvious, and while at the equator a degree of longitude amounts to 69.652 miles, at latitude 40°, or ap-

proximately that of New York (40° 43′), it would equal 53.431 miles and at the north pole it would decrease, of course, to zero.

Newton in his researches on gravitation, by comparing the attraction exerted by the Earth with that of the Sun and other bodies, was able to connect its mass with that of the planets and Sun. The problem of determining the mass of the whole Earth in terms of a given terrestrial body—that is, in tons, pounds or kilograms—was indeed a serious one, and it was first attacked in Great Britain by Nevil Maskelyne (1732-1811), who was Astronomer Royal. If we know the volume of the Earth and its density, referred to some standard as water, air or iron, it is of course easy to determine its mass. But the determination of its density is no less a problem than the determination of its mass directly. It is possible, of course, to compute the relative amount of water, but this gives only a small amount of the mere surface of the Earth. We can descend in mine shafts a mile or more and investigate the nature of the material, but this again affords no clue to the thousands of feet of materials below, so that an estimate of the average density based on such data cannot be considered at all trustworthy. Newton, taking into consideration the various elements of the Earth, estimated its density at between five and six times that of water. Maskelyne, however, bearing in mind the phenomenon of the deflection of the plumb-line observed by Bouguer and La Condamine in their expedition to measure an arc of latitude in Peru (a phenomenon caused by the attraction of the mountain Chimborazo), selected the narrow ridge of Schehallien in Perthshire and found that the attraction of the mountain caused a deflection of about 12″ on each side of the ridge. This attraction of the mountain as compared with the attraction of the Earth on the plumb-bob enabled a value for the density of the Earth of about 4½ times that of water to be obtained. It remained for the famous Cavendish experiment, carried out by Henry Cavendish (1731-1810), to substitute for the mountain a pair of heavy balls. This gave a value for the density of the Earth of 5½ times that of water, a value confirmed by numerous repetitions of Cavendish's classical experiment. Expressed in pounds, the mass of the Earth is a little more than 13 billion billion, a figure that the human mind utterly fails to grasp.

There must have been a time when the Earth contained much more heat than at present. The Sun is not supplying heat enough to make good the losses sustained by the globe. These losses must have been taking place over a period of countless years. One is forced to believe that not only once was our Earth much hotter than at present, but that its temperature was a red heat. Going back still further, the now solid globe must have been actually a molten mass. Being a molten mass, it is not difficult to realize that it readily assumed a

globular form on its journey through space. A falling drop of rain is a globe; a drop of oil suspended in a liquid with which it does not mix has a spherical shape. Therefore if a mass of material as large as the Earth were so soft that its individual particles obeyed the forces of attraction exerted by each part of the mass on all the other parts, it is quite obvious that it would assume a globular shape, especially under the influence of motion. If this great sphere were caused to rotate around an axis, like a ball of clay on a potter's wheel, any lack of true sphericity would not only be overcome, but there would be a tendency for the molten body to bulge at the equator and flatten down at the poles, forming an oblate spheroid such as by actual measurement the Earth is found to be. Indeed, not only is the Earth an oblate spheroid, but most of the planets which can be measured have become flattened at the poles for the same reason.

In connection with the spheroidal shape of the Earth, mention should be made of a recent theory which seeks to demonstrate that the shape of the Earth is being transformed into a polyhedral form, or more exactly, that there is a tendency in the direction of its assuming the figure of a regular tetrahedron, or four-sided figure, each of whose faces is triangular. This is manifested by the lithosphere or solid portion of the Earth. The water is massed on the faces of such a tetrahedron, the force of gravity acting most powerfully at the center of each of the four surfaces. The tetrahedron hypothesis assumes that a more or less solid crust was formed when the Earth was still perhaps in an approximately spheroidal form. As contraction occurred in the interior the external shell proved too large. Hence a different form has to be assumed, which, it is asserted, would be the tetrahedral. On each of the faces of such a tetrahedron one of the four oceans would lie, the Arctic Ocean being assumed as the fourth for the region about the North Pole. The continents would correspond with North and South America, Euro-Africa, Asia-Australia and Antarctica. This hypothesis is borne out in many respects by geological and other considerations. First advanced in the 70's of the nineteenth century by Lowthian Green, the hypothesis has been put forward in recent years with further developments and attempts at its proof, so that it is considered as a tenable and possible explanation, tho its absolute soundness has not been demonstrated.

Recognizing and proving the spherical shape of the Earth by no means explains the apparent motion of the Sun, Moon and stars as regards the planet. As the nature of the solar system was developed by Copernicus and Newton, people were compelled to recognize that the Earth revolved around the Sun, and, furthermore, that it rotated daily about its axis.

These motions are necessary to explain various phenomena. For

example, when a body moves in a circle a force is needed to act on it, pulling toward the center proportionally to the square of the rate of spin and proportionally to the distance. Every pound of mass in the Moon would need a pull equal to about the weight of 3 ounces to keep it in a circle which it traveled around once in 24 hours. Every pound in the Sun would need a pull about three-quarters of a hundredweight. The nearest fixed star would need a pull on every pound, of about 9,000 tons. One cannot imagine that the Earth could exert such forces and so are obliged to think that the Earth is revolving and not the sky.

Final proof of the rotation of the Earth was furnished in the middle of the last century by Foucault. His experiments are constantly repeated in physical laboratories and experimental lectures. From the dome of the Pantheon in Paris he suspended a heavy ball by a fine cord and caused it to swing in a single plane. The path of the ball across the floor could be traced, and it was found that after it had been in vibration for some time it was swinging in a different direction from that in which it had started. The reason was that the floor had revolved under the ball with the rotation of the Earth.

The daily rotation of the Earth on its axis and its yearly rotation about the Sun supply us with our means of measuring time. According to Professor Polynting, "The Earth is a clock, the line to the Sun is the finger and the sky is the face. But the Sun is not a regular timekeeper. Our twenty-four-hour day is only the average between successive noons or times when the Sun is due south. If compared with a good clock, the Sun is in parts of the year too soon and in other parts too late, sometimes as much as a quarter of an hour. This cannot be due to change in the Earth's rate of spin, for to change a spin there must be either a force acting at one side of the center of gravity or a change of shape. The forces on the Earth exerted by the Sun and Moon act almost exactly through the center of gravity and so affect the rate of spin hardly at all. The Earth does not change its shape sufficiently to account for the variation in the solar day.

"The variation in the solar day is due partly to the inclination of the Earth's axis to the plane in which it moves around the Sun, partly to variation of the Earth's motion round the Sun at different times of the year.

"The fixed stars keep good time, getting round in about 4 minutes less than 24 hours. By them clocks are rated. Their day is the true time of one revolution of the Earth."

Among the movements of the Earth there is one that is so minute as to be of peculiar interest to the astronomer. It is a small displacement or wobbling of the axis of the Earth or theoretical pole. This pole shifts its place through a circle of some few yards in diameter

in the course of a period of somewhat over a year, and as a result there is a variation of latitude on the Earth's surface. This was discovered first in 1884 and 1885 by Dr. Küster at Berlin, and after observations made at various stations by members of the International Geodetic Association in 1888, it was found that this synchronous variation was occurring in a periodic manner at a number of stations. The general nature of the occurrence was defined by Prof. S. C. Chandler in 1891, who stated that the pole of the Earth might be supposed to describe a circle with a radius of 30 feet in a period of fourteen months. One reason assigned for this phenomenon is a change in the distribution of mass, due to the temporary occurrence of heavy falls of snow or rain limited to one continent, or to the transportation of great bodies of air and water from place to place by atmospheric or ocean currents, so that the globe is made slightly lopsided and temporarily to forsake its normal axis. Also it has been supposed that the Earth is not absolutely rigid. As a quasi-plastic mass it would yield to certain strains which tend to protract the time of circulation of the displaced pole. In fact, in all considerations of the various phenomena of gravitation and tides we have to recognize that in practice the astronomer of to-day is not dealing with the theoretically rigid body of Newton and the earlier mathematicians.

One of the important conditions of the rotation of the Earth is that it moves around an axis which is not vertical but which is inclined toward the plane of its orbit. Dolmage in his volume, "Astronomy of To-day," tells us that "If the axis of the Earth stood 'straight up,' so to speak, while the Earth revolved in its orbit, the Sun would plainly keep always on a level with the equator. This is equivalent to stating that, in such circumstances, a person at the equator would see it rise each morning exactly in the east, pass through the zenith—that is, the point directly overhead of him at midday—and set in the evening due in the west. As this would go on unchangingly at the equator every day throughout the year, it should be clear that, at any particular place upon the Earth, the Sun would in these conditions always be seen to move in an unvarying manner across the sky at a certain altitude, depending upon the latitude of the place. Thus the more north one went upon the Earth's surface the more southerly in the sky would the Sun's path lie, while at the north pole itself the Sun would always run round and round the horizon. Similarly the more south one went from the equator the more northerly would the path of the Sun lie, while at the south pole it would be seen to skirt the horizon in the same manner as at the north pole. The result of such an arrangement would be that each place upon the Earth would always have one unvarying climate, in which case there would not exist any of those beneficial changes of season to which we owe so much.

"The changes of season which we fortunately experience are due,

however, to the fact that the Sun does not appear to move across the sky each day at one unvarying altitude, but is continually altering the position of its path, so that at one period of the year it passes across the sky low down, while at another it moves high up across the heavens and is above the horizon for a much longer time. Actually the Sun seems little by little to creep up the sky during one-half of the year, namely, from mid-winter to mid-summer, and then just as gradually to slip down it again during the other half, namely, from mid-summer to mid-winter. It will therefore be clear that every region of the Earth is much more thoroly warmed during one portion of the year than during another—*i.e.*, when the Sun's path is high in the heavens than when it is low down.

"Once more we find appearances exactly the contrary from the truth. The Earth is in this case the real cause of the deception, just as it was in the other cases. The Sun does not actually creep slowly up in the sky and then slowly dip down it again, but owing to the Earth's axis being set aslant, different regions of the Earth's surface are presented to the Sun at different times. Thus in one portion of its orbit the northerly regions of the Earth are presented to the Sun and in the other portion the southerly. It follows, of course, from this that when it is summer in the northern hemisphere it is winter in the southern and vice versa.

"The fact that in consequence of this slant of the Earth's axis the Sun is for part of the year on the north side of the equator and part of the year on the south side leads to a very peculiar result. The path of the Moon around the Earth is nearly on the same plane with the Earth's path around the Sun. The Moon, therefore, always keeps to the same regions of the sky as the Sun. The slant of the Earth's axis thus regularly displaces the position of both the Sun and the Moon to the north and south sides of the equator respectively in the manner we have been describing. Were the Earth, however, a perfect sphere such change of position would not produce any effect.

"At present the north pole of the heavens is quite close to a bright star in the tail of the constellation of the Little Bear, which is consequently known as the pole star, but in early Greek times it was at least ten times as far away from this star as it is now. After some 12,000 years the pole will point to the constellation of Lyra, and Vega, the most brilliant star in that constellation, will then be considered as the pole star. This slow twisting of the Earth is technically known as precession, or the precession of the equinoxes.

"We have seen that the orbit of the Earth is an ellipse and that the Sun is situated at what is called the focus, a point not in the middle of the ellipse, but rather toward one of its ends. Therefore during the course of the year the distance of the Earth from the Sun varies. The Sun, in consequence of this, is about 3,000,000 miles nearer to us

in our northern winter than it is in our northern summer, a statement which sounds somewhat paradoxical. This variation in distance, large as it appears in figures, can, however, not be productive of much alteration in the amount of solar heat which we receive, for during the first week in January, when the distance is least, the Sun only looks about one-eighteenth broader than at the commencement of July, when the distance is greatest. The great disparity in temperature between winter and summer depends, as we have seen, upon causes of quite another kind, and varies between such wide limits that the effects of this slight alteration in the distance of the Sun from the Earth may be neglected for practical purposes."

The most striking effect of gravitation in its universal aspect is seen on the Earth in the case of the tides, which are due to the attraction of the Moon on the Earth and especially on the waters of its oceans. While the ancients could not explain the cause of the daily change in the tides, the phenomenon was obvious to all mariners or those dwelling by the sea or even on great rivers. The connection of the Moon with this phenomenon, it is claimed, was understood as early as 1000 B.C. by the Chinese, for at full and new moon exceptionally high tides were observed, and the name of spring tides was applied as contrasted with the minimum high water which was observed at the near tides at the second and fourth quarters of the Moon. Not only the Chinese but the Greeks and Romans noticed this same phenomenon, and Julius Cæsar in his "Commentaries" tells us that when he was embarking his troops for Britain the tide was high because the Moon was full, while both Pliny and Aristotle connect the time of high water with the age of the Moon. The connection between the Moon and the tide was thus early established and practically applied by navigators, who were quick to realize the nature of the phenomenon, even tho they and the astronomers were unable to present any satisfactory explanation.

A general explanation of the tides as due to the disturbing action of the Moon and Sun, especially the former, was put forward by Newton. Newton's explanation, as described by Berry in his "Short History of Astronomy," was as follows: "If the Earth be regarded as made of a solid spherical nucleus, covered by the ocean, then the Moon attracts different parts unequally, and in particular the attraction, measured by the acceleration produced on the water nearest to the Moon, is greater than that on the solid Earth and that on the water farthest from the Moon is less. Consequently the water moves on the surface of the Earth, the general character of the motion being the same as if the portion of the ocean on the side toward the Moon were attracted and that on the opposite side repelled. Owing to the rotation of the Earth and the Moon's motion, the Moon returns

to nearly the same position with respect to any place on the Earth in a period which exceeds a day by (on the average) about 50 minutes, and consequently Newton's argument showed that low tides (or high tides), due to the Moon, would follow one another at any given place at intervals equal to about half this period; or, in other words, that two tides would in general occur daily, but that on each day any particular phase of the tides would occur on the average about 50 minutes later than on the preceding day, a result agreeing with observation. Similar but smaller tides were shown by the same argument to arise from the action of the Sun and the actual tide to be due to the combination of the two. It was shown that at new and full moon the lunar and solar tides would be added together, whereas at the half moon they would tend to counteract on another, so that the observed fact of greater tides every fortnight received an explanation. A number of other peculiarities of the tides were also shown to result from the same principles."

From Newton's time to the present the tides have supplied material for astronomical and mathematical research, so that through the efforts of many astronomers and other scientists their theory and occurrence are now well understood, and the various governments make ample provision through hydrographic offices and otherwise to provide such information for mariners. In the theoretical discussion in modern times one name stands out prominently, that of Sir George H. Darwin, of England, whose researches on the tides of the Earth have developed to a point where they have a most important bearing on cosmical theory.

It is desirable here to outline the chief features of tides in their everyday occurrence. The term "flood-tide" is applied to the rising water, which reaches "high-water" mark at the moment when the tide is highest, while in falling the tide is said to "ebb" until low water, or the lowest mark, is reached. Near the times of new and full moon occur the "spring tides," which are the highest tides of the month as distinguished from the "neap-tides," which are the smallest, occurring when the Moon is in quadrature, the relative heights of spring and neap-tides being as about 7 to 4. At the time of "spring-tides" the interval between the corresponding tides of successive days is less than the average value of 24 hours and 51 minutes and the tides are said to "prime," the interval amounting to about 24 hours and 38 minutes, while at "neap-tides" the interval increases to 25 hours and 6 minutes, and then the tides are said to "lag." The highest tides of all occur when the new or full moon occurs at the time the Moon is in perigee, especially as this takes place about January 1st, when the Earth is nearest to the Sun.

Not only are the tides interesting for their relation to navigation,

but on account of their intimate connection with the motion of the Earth. The daily movement of the tides is a drag on the energy of our planet and is acting to cut down its speed of rotation. If the speed of rotation of the Earth diminishes it is obvious that our day is being lengthened, that to-day is longer than yesterday and that to-morrow will be longer than to-day, even tho these increases are all but inappreciable in the time that the human mind can fathom. Sir Robert Ball in his "Story of the Heavens" summarizes the variation wrought by the tides in the following paragraph: "Let us take a glance back into the profound depths of times past and see what the tides have to tell us. If the present order of things has lasted, the day must have been shorter and shorter the farther we look back into the dim past. The day is now twenty-four hours; it was once twenty hours, once ten hours, and once six hours. How much farther can we go? When the six hours is past, we begin to approach a limit which must at some point bound our retrospect. The shorter the day the more is the Earth bulged at the equator; the more the Earth is bulged at the equator the greater is the strain put upon the materials of the Earth by the centrifugal force of its rotation. If the Earth were to go too fast it would be unable to cohere together; it would separate into pieces, just as a grindstone driven too rapidly is rent asunder with violence. Here, therefore, we discern in the remote past a barrier which stops the present argument. There is a certain critical velocity which is the greatest that the Earth could bear without risk of rupture, but the exact amount of that velocity is a question not very easy to answer. It depends on the nature of the materials of the Earth; it depends upon the temperature; it depends upon the effect of pressure and on other details not accurately known to us. An estimate of the critical velocity has, however, been made, and it has been shown mathematically that the shortest period of rotation that the Earth could have, without flying into pieces, is about three or four hours. The doctrine of tidal evolution has thus conducted us to the conclusion that at some inconceivably remote epoch the Earth was spinning around its axis in a period approximating to three or four hours."

The existence of tides in the solid Earth, as well as in the oceans, was first indicated by Lord Kelvin in 1867. The first numerical estimate of the amount of the tidal oscillations of the solid Earth was made by Sir George H. Darwin in 1882 and was based on an indirect method and resulted from observation of the tides of the ocean. Further indirect methods were successfully applied later, with more complete data.

Sir George H. Darwin has expressed the opinion that we may now feel confident that the Earth yields to the tidal forces to the same de-

gree as would a steel globe. It is impossible to give an accurate measurement of the amount of the vertical motion of the Earth's surface, but it is probably that at spring tides in the latitude of New York, the surface of the solid Earth moves up and down through about six inches. Hayford's work on isostatic equilibrium, and its influences on Modern Geology, will be found in a later volume of this series.

CHAPTER XIV

THE MOON

THAT the Moon is the nearest the Earth of all the heavenly bodies is one of the most obvious facts which confront the star-gazer. Its regular motion must have been early appreciated by primitive man, after he had realized that the rising and setting of the Sun marks regularly recurrent intervals of time. As he was able to reflect upon his observations and properly to coördinate them, he doubtless noted the connection between the form of the Moon and its position in the sky with respect to the Sun. For by keeping count with pebbles or rude notches cut in a stick he would learn that the interval of time between recurring full moons was always the same, and that the series of changes he could observe followed in regular order. Thus when the Moon appeared after sunset near the place where the Sun had disappeared he saw a thin crescent, the hollow side of which was turned away from the Sun. A little later the Moon set.

The next night he observed the Moon further from the Sun, with a thicker crescent, and noted also that it set later, an effect that gradually increased until the semi-circular disk, with the flat side turned away from the Sun, was seen in rather less than a week after the first appearance of the crescent. In another week the semi-circle enlarged to a complete disk and the Moon rose about sunset and set about sunrise, being in a direction nearly opposite to that of the Sun. From this time on the size again diminished; the semi-circular form was seen once more with the flat side still turned away from the Sun and toward the west instead of the east as the Moon approached the Sun on the other side, rising before it and setting in the daytime. Again he saw the crescent and marked that the time of rising approached that of sunrise, until the Moon became altogether invisible. Two or three nights intervened and the new Moon reappeared, whereupon the whole series of changes was repeated. In other words, this primitive man must have formulated a lunar month.

All ancient records recognize this lunar month of twenty-nine and a half days, and that interval must have been adopted long before the year. By the time of Chaldean and Egyptian astronomy, however, the year was known, so that the first conception of the lunar month is lost in the mists of antiquity. The Chaldeans studied the

motions of the Sun and the Moon. Their calendar records, which they seem to have maintained with considerable care, enabled them to discover that eclipses occurred after a period known as the Saros, consisting of 6,585 days.

The nature of the Moon was, of course, to them a mystery. It was known to move around the sky. The Babylonians supposed that, having a bright and a dark side, the different phases were caused by the bright side's coming more and more into view during its movement around the sky. In the seventh century Pythagoras taught more correctly that the Moon, like other heavenly bodies, was spherical, and that it was bright because it received the light of the Sun. The phases, he rightly judged, were due to a greater or less amount of the illuminated half turned toward us, and the curve forming the boundary between the bright and dark portions of the Moon was to him conclusive evidence of a spherical shape. He was later supported in his theory by Aristotle, who made a similar clear and definite statement of the reason for the phases of the Moon.

Perhaps the first systematic study of the Moon was that of Aristarchus, a famous member of the Alexandrine school, who flourished in the first half of the third century and wrote a treatise "On the Magnitudes and Distances of the Sun and Moon," which still survives. Taking the Moon when it was half full, so that a line drawn to it from the Sun made a right angle with a line from the Moon to the Earth, by measuring the angle between the Moon and the Sun he was able to determine the ratio of the sides of this triangle and the relative distance of the Moon and the Sun from the Earth. While the method of Aristarchus was ingenious, yet the result he obtained, that the Sun was 18 to 20 times as far distant as the Moon, was sadly in error, for the actual distance is nearly four hundred times. Still the difficulties in the way of accurate observation were enormous for lack of proper instruments. Aristarchus also took advantage of the solar eclipse to ascertain the distances of these two bodies, and reasoned correctly that when the Moon sometimes rather more than hides the surface of the Sun and sometimes does not quite cover it, their diameters must vary as their real distances. He even obtained by eclipse observations a value for the diameter of the Moon in terms of that of the Earth. What would have been an excellent approximation was marred, however, by an incorrect estimate of the apparent size of the Moon, which he took as two degrees instead of one-half a degree. Nevertheless this work was an important advance in practical astronomy. It paved the way for Hipparchus, who discussed the motions of the Moon, motions which, long before his time, were known to be irregular and much more complicated than those of the Sun. The path of the Moon is always changing and its motions are subject to variation.

Hipparchus notes that the part of the Moon's path in which the motion is most rapid is not always in the same position on the celestial sphere, but moves continuously. He was able to realize the different motions of the Moon, to distinguish the various months based upon them and to employ the Chaldean and other early eclipse observations for determining the position of the Moon at various earlier epochs. Hipparchus really evolved a most complicated set of motions. He was aware of the shortcomings of his theory, but was unable to reconstruct it in a satisfactory manner. Following out the eclipse method of Aristarchus, Hipparchus made a determination of the relation between the distances of the Sun and Moon, measuring their angular diameters, and found that the distance of the Moon is nearly 59 times the radius of the Earth. Combining this figure for the distance of the Sun with that of Aristarchus, a value of 1,200 times the radius of the Earth was obtained, which value was employed for many centuries.

Ptolemy, in the fourth book of the "Almagest," discusses the length of the month with the theory of the Moon and makes the important announcement of a further inequality in the Moon's motion, which Hipparchus had only suspected and which was due in large part to its position with respect to the Sun. This was later termed "evection" and involved a still further complication of the mathematical computations of Hipparchus because it meant the use of an epicycle and a deferent, which was itself a moving eccentric circle, the center of which revolved around the Earth. Ptolemy's mathematics and ingenuity were able to fit his theory to observations. Altho his work showed many inconsistencies which, great as he was, he was unable to control, nevertheless it represented a notable development in astronomy. To Ptolemy is due the parallax method for obtaining the distance of the Moon by observing its direction from two points on the Earth's surface and by finding the distance between these two points in terms of the Earth's radius. This distance of the Moon he estimated was 59 times the radius of the Earth. With this value, according to the method of Hipparchus just mentioned, he computed the distance from the Earth to the Sun. He found that the distance was 1,210 times the radius of the Earth, which value was equally in error as compared with the modern figure. The actual distance is about twenty times this amount.

So readily were the motions of the Moon observed and so carefully were the records maintained that even at an early date much was known about its motions. These data enabled much calculation of the Moon's motion to be carried on, so that early mathematical astronomy dealt with the Moon in no small degree. Various irregularities of its motion and appearance were discussed, and practically all of the notable astronomers made some contribution to

our knowledge of the satellite. Even an outline of these discussions would lead the reader far afield into the depths of mathematics, for which reason it is possible to mention only a few of the important researches and to indicate merely their general nature. The study of the Moon had a practical importance, however, as lunar positions were early used to determine longitude in navigation and lunar tables were calculated by government and other astronomers.

Nowhere was there more interest manifested in the problem of the motion of the Moon than at Greenwich Observatory, where the matter had always been a specialty of that institution. "It is a curious fact," states the late Professor Newcomb in his "Reminiscences of an Astronomer," "that while that observatory supplied all the observations of the Moon, the investigations based upon these observations were made almost entirely by foreigners, who also constructed the tables by which the Moon's motion was mapped out in advance. The most perfect tables made were those of Hansen, the greatest master of mathematical astronomy during the middle of the century, whose tables of the Moon were published by the British Government in 1857. They were based on a few of the Greenwich observations from 1750 to 1850. The period began with 1750, because that was the earliest at which observations of any exactness were made. Only a few observations were used, because Hansen, with the limited computing force at his command—only a single assistant, I believe—was not able to utilize a great number of the observations. The rapid motion of the Moon, a circuit being completed in less than a month, made numerous observations necessary, while the very large deviations in the motion produced by the attraction of the Sun made the problem of the mathematical theory of that motion the most complicated in astronomy. Thus it happened that, when I commenced work at the Naval Observatory in 1861, the question whether the Moon exactly followed the course laid out for her by Hansen's tables was becoming of great importance.

"For a year or two our observations showed that the Moon seemed to be falling a little behind her predicted motion. But this soon ceased, and she gradually forged ahead in a much more remarkable way. In five or six years it was evident that this was becoming permanent; she was a little farther ahead every year. What could it mean? To consider this question, I may add a word to what I have already said on the subject.

"In comparing the observed and predicted motion of the Moon, mathematicians and astronomers, beginning with Laplace, have been perplexed by what are called 'inequalities of long period.' For a number of years, perhaps half a century, the Moon would seem to be running ahead and then she would gradually relax her speed and fall behind. Laplace suggested possible causes, but could not prove

them. Hansen, it was supposed, had straightened out the tangle by showing that the action of Venus produced a swinging of this sort in the Moon; for one hundred and thirty years she would be running ahead and then for one hundred and thirty years more falling back again, like a pendulum. Two motions of this sort were combined together. They were claimed to explain the whole difficulty. The Moon, having followed Hansen's theory for one hundred years, would not be likely to deviate from it. Now it was deviating. What could it mean?

"Taking it for granted, on Hansen's authority, that his table represented the motions of the Moon perfectly since 1750, was there no possibility of learning anything from observations before that date? As I have already said, the published observations with the usual instruments were not of that refined character which would decide a question like this." But observations of stars which might be available, and which had been made in many instances, would have an important bearing on this work. For if an occultation or passage of the Moon between a star and the Earth occurred and its time registered, the path of the Moon in the heavens and the time at which it arrives at each point of the path would be determined if the time of the occultation was known within one or two seconds. Professor Newcomb continues: "It was not until after the middle of the century (seventeenth), when the telescope had been made part of the astronomical instruments for finding the altitude of a heavenly body, and after the pendulum clock had been invented by Huygens, that the time of an occultation could be fixed with the required exactness. Thus it happens that from 1640 to 1670 somewhat coarse observations of the kind are available, and after the latter epoch those made by the French astronomers become almost equal to the modern ones in precision.

"The question that occurred to me was, Is it not possible that such observations were made by astronomers long before 1750? Searching the published memoirs of the French Academy of Science and the Philosophical Transactions, I found that a few such observations were actually made between 1660 and 1700. I computed and reduced a few of them, finding with surprise that Hansen's tables were evidently much in error at that time. But neither the cause, amount or nature of the error could be well determined without more observations than these. Was it not possible that these astronomers had made more than they had published? The hope that material of this sort existed was encouraged by the discovery at the Pulkowa Observatory of an old manuscript by the French astronomer Delisle, containing some observations of this kind. I therefore planned a thoro search of the old records in Europe to see what could be learned."

By good fortune suitable observations were found at the Paris Observatory and their relations and the method of making were studied and everything necessary was copied. The work took some six weeks, but Professor Newcomb says, "The material I carried away proved the greatest find I ever made. Three or four years were spent in making all the calculations I have described. Then it was found that seventy-five years were added, at a single step, to the period during which the history of the Moon's motion could be written. Previously this history was supposed to commence with the observation of Bradley at Greenwich, about 1750; now it was extended back to 1675, and with a less degree of accuracy thirty years farther still. Hansen's tables were found to deviate from the truth in 1675 and subsequent years to a surprising extent, but the cause of the deviation is not entirely unfolded even now.

"One curious result of this work is that the longitude of the Moon may now be said to be known with greater accuracy through the last quarter of the seventeenth century than during the ninety years from 1750 to 1840. The reason is that, for this more modern period, no effective comparison has been made between observations and Hansen's tables."

As the Moon rotates around the Earth while the Earth is passing in its orbit about the Sun, it will be obvious that twice in its journey the Sun must come into a line of intersection of the Moon's orbit with that of the Earth. When this happens at the time of full moon the Earth will lie directly between the Moon and the Sun, so that the light from the Sun is intercepted and a shadow is formed on the Moon's surface. Sometimes the Moon only partially enters the Earth's shadow and then the eclipse, as this phenomenon is termed, is partial. If, however, the Sun is situated on the line of intersection at the time of new moon, then the Sun will be eclipsed, and a solar eclipse so rich in astronomical significance occurs. Solar eclipses have been discussed elsewhere and their importance explained. Lunar eclipses, besides enabling us to check the motions of the Moon and furnishing an interesting spectacle, afford little scientific information.

When the black shadow on the Moon is first detected in the case of a total lunar eclipse, it is interesting to watch its encroachment until the entire surface of the satellite is covered. Even the Moon, on which no direct sunlight can fall, is often visible, glowing with a copper-colored hue, sufficiently bright to enable several of the markings on the surface to be seen. This is due to refraction of the atmosphere, which bends the sunbeams that have just grazed the Earth and permits them to fall within the shadow. In their journey through the denser atmosphere they have become rich in red rays, which gives to the disk a ruddy or copper-like hue analogous to that of the Sun at sunrise or sunset. Whether the eclipse of the Moon is total or partial

depends on the extent to which it passes into the shadow of the Earth, as the accompanying diagram will indicate clearly. Lunar eclipses are useful to the astronomer for determining the length of the synodic month and also for determining the temperature to which the Moon has been raised, for when it enters the shadow all direct light from the Sun is cut off and the Moon becomes cold very rapidly. Furthermore, the position of the Moon with respect to the stars can be determined on such occasions with great accuracy. Like solar eclipses, eclipses of the Moon can be predicted with high precision, and they are regularly announced in almanacs and ephemerides.

The Moon always presents the same face to the Earth, a phenomenon discovered by Galileo. It must follow that the Moon rotates on its axis once in the same number of seconds that it requires for a revolution around our planet. This is explained by the fact that tides on the Moon, as in the case of the Earth, have lengthened the period of rotation by their braking action. At a time when the Moon was still a hot, semi-molten mass, the attraction of the Earth produced great tides, not tides of water, but tides of molten rock. These tides on the Moon checked its rotational velocity and eventually constrained the Moon to rotate on its axis in precisely the same period as that which it requires to revolve around the Earth. All this happened eons ago. There is no longer evidence of any tidal action, because the Moon is frozen. Altho there can hardly be tides on the Moon, yet there may be tides in the Moon.

"It may be that the interior of the Moon is still hot enough to retain an appreciable degree of fluidity," writes Sir Robert Ball, "and if so, the tidal control would still retain the Moon in its grip; but the time will probably come, if it has not come already, when the Moon will be cold to the center—cold as the temperature of space. If the materials of the Moon were what a mathematician would call absolutely rigid, there can be no doubt that the tides could no longer exist, and the Moon would be emancipated from tidal control. It seems impossible to predicate how far the Moon can ever conform to the circumstances of a rigid body, but it may be conceivable that at some future time the tidal control shall have practically ceased. There would then be no longer any necessary identity between the period of rotation and that of revolution. A gleam of hope is thus projected over the astronomy of the distant future. We know that the time of revolution of the Moon is increasing, and so long as the tidal governor could act, the time of rotation must increase sympathetically. There will then be nothing to prevent the rotation remaining as at present, while the period of revolution is increasing. The privilege of seeing the other side of the Moon, which has been withheld from all previous astronomers, may thus in the distant future be granted to their successors."

While study of the Moon and its motions continued, a beginning was made in the Renaissance to examine the surface of this satellite. Leonardo da Vinci (1452-1519) was the first to explain correctly the dim illumination seen over the rest of the surface of the Moon when the bright part was only a thin crescent. This he maintained is due to the earthshine or slight illumination of the Moon by light reflected from the Earth, just as moonshine is able to illuminate the Earth.

Galileo's lunar observations through his telescope were epoch-making. Not only was he able to disprove many common conceptions of the nature of the satellite and its surface, but also to present a mass of evidence of a positive character. In spite of the familiar dark markings, the Moon was really supposed to be a smooth sphere. After the introduction of the telescope, however, it was recognized by Galileo that the surface of the Earth's satellite was dotted with various inequalities, which he assumed to be mountains, valleys and seas. Thus he correctly accounted, in part at least, for the unevenness of the surface. He was not content with mere observation of the features of the Moon's surface, but measured the height of some of the more conspicuous lunar mountains and obtained for them an estimated elevation of four miles, a figure which agrees fairly well with modern estimates. Having seen and measured mountains on the Moon's surface, it seemed natural that there should be water. The large dark spots he erroneously regarded as seas, altho he was not responsible for the corresponding names applied to these supposed expanses of water by some of his successors, and still preserved in lunar maps. The chief marks of astronomical progress as revealed by Galileo's observation of the Moon were that it was a body in many respects similar to the Earth, that it was not a perfect sphere, and that there is no fundamental difference between celestial bodies and our own Earth, either in their motions or in their general nature, which was important in the final establishment of the Copernican theory.

One other discovery of Galileo's in connection with the Moon is of great importance. It had been known for many years that as the Moon revolved around the Earth the same markings were constantly seen. With the telescope these markings could be studied so much more distinctly that it occurred to Galileo to ascertain whether there was any change in the Moon's disk, or whether its appearance was always exactly the same. He found that as the Moon moves in its orbit arount the Earth slight changes are seen in its appearance. In other words, small portions of the hemisphere alternately on its northern and southern half are exposed. The simplest of the motions of the Moon in this way subsequently came to be known as "librations."

Kepler in his Epitome of the Copernican astronomy demonstrated

that his planetary laws applied to the motion of the Moon around the Earth, despite irregularities which introduced enormous complications. In this work, however, he devotes much attention to the theory of the Moon, explaining in considerable detail both evection and variation.

Galileo established the fact that the Moon was similar to the Earth in many respects. The analogy was carried somewhat further by certain of the pioneer workers with large telescopes. Even Herschel held that because the Moon closely resembled the Earth, it might be a suitable habitat for human beings. The dark spots once taken for seas and bearing that name on lunar maps are, in reality, lava, while the craters which dot the surface of the satellite, with one or two possible exceptions, belong to volcanoes long since extinct. The dark lines once known as "rills," which was assumed were rivers, are plainly without water. If there is a lunar atmosphere its density must be very small, in fact less than that of the atmosphere far above the Earth. That there is a very rare lunar atmosphere seems to be probable. In fact, the assumption of an atmosphere is necessary for the explanation of certain phenomena.

After Galileo's lunar studies the next important work was that of John Hevel, of Danzig (1611-1687), who published in 1647 his Selenographia, in which not only the text but the plates were prepared by him. Here he systematically describes and names the chief features of the Moon, the immense craters and seas, employing many names taken from the Earth, such as Apennines, Alps, and Mare Serenitatis for the Pacific Ocean, all designations still found on modern lunar maps. Not all of his names have survived. John Baptist Riccioli (1598-1671), in a treatise on astronomy called The New Almagest, 1651, gave to various mountains and craters the names of distinguished men of science and philosophers. Hence the names of Plato, Archimedes, Tycho and Copernicus are found on lunar maps. These names have survived in considerable number. More modern map-makers, such as Beer and Maedler, whose map was published in 1837, and Schmidt of Athens, who published a map of the Moon seven feet in diameter in 1878 have carried out this idea. Modern astronomers are likewise honored with the names of various points represented on the maps.

For the origin of the Moon the mind must be forced to look back millions and millions of years to a time when our Earth existed in a very different form. Then it was not a solid mass, but a globe of molten material on which floated a crust perhaps some thirty-five miles thick. It rotated not in a period of 24 hours, the present day's length, but at a terrific velocity which may have made the day some three hours in length. Such a speed of revolution naturally produced a most powerful centrifugal force. One day a cataclysm occurred.

Five thousand cubic millions of miles of matter were thrown off into space. Thus the Moon was born. A great scar was left on the surface of the Earth, a scar which in the opinion of Professor William H. Pickering is the basin of the Pacific Ocean. After this rending of the Earth the remaining parts of the crust, afloat on the liquid interior, were split along irregular lines into two pieces, which drifted apart and were filled by the waters of the Atlantic and Pacific Oceans. This theory of Pickering's is diametrically opposed to that of Professor T. J. J. See, who claims that the Moon is in reality a planet, captured by the Earth in its wanderings through space, and that all satellites have been thus captured.

Whatever the origin of the Moon, it is the largest of all the planetary satellites, yet smaller in mass than the Earth, from which it is separated by a distance that varies between 222,000 and 253,000 miles. Its gravity is equal to about one-sixth that of the Earth, for which reason the same amount of energy acting, for example, in a volcanic upheaval, produced mountains higher than those on the Earth. This mass of the Moon is about 1/80 that of the Earth, or 73,000,000,000,000 tons.

The diameter of our planet is 7,914 miles, while that of the Moon is 2,160 miles, so that the diameters stand very nearly in the relation of 4 to 1, while the superficial area of the Moon is equal to about 1/13 part of the surface of the Earth. The average distance of the Moon from the Earth is also fairly constant, and the average fluctuations do not exceed more than about 13,000 miles on either side of its mean value of 239,000 miles.

The Moon is essentially a dead planet in the eyes of most astronomers. Its fires long since have been extinguished. It is a great globe of chilled slag. Its craters have no counterpart on the Earth. The lunar crater is a great circular plane, 50 or even 100 miles in diameter, around which rises a precipice perhaps five or ten thousand feet, while in the center there may be a hill or two about half as high. Thousands of these volcanoes are visible in the telescope. How these craters were formed is a puzzle. Some astronomers hold that they mark the impact of countless meteorites. Others assume them to be the product of gigantic bubbles in a once molten mass that burst. Again it is claimed that they are volcanoes resembling those of the Earth.

Most astronomers tell us that the craters have long been dead, that the Moon has had for centuries no atmosphere and therefore cannot have water or support plant or animal life. Prof. William H. Pickering, however, tells us of an exceedingly rare lunar atmosphere and maintains that the Moon's craters are not all extinct. He even claims that certain great white expanses are snow and ice, and, furthermore, that there is evidence of the growth and decay of vegetation.

To support his views of vanishingly feeble volcanic activity he calls attention to the little crater named Linné, after the famous naturalist, Linnæus. In modern times this crater has unquestionably undergone changes. Only a few centuries ago it was described on the old maps as "a crater of moderate size" and later as "a very small round brilliant spot." A dead volcano cannot alter its shape.

If there are still a few intermittently active volcanoes they must expel water and carbonic acid gas, judging by earthly volcanoes. But water cannot be found on the Moon as a liquid, for the temperature of its surface is probably not far from 460° F. below zero. Many of the elevated peaks are capped with a silver glow, which also characterizes the lining of the "craterlets." In Pickering's eyes that white sheen is snow. He believes also in accumulations of snow and ice at the poles. If carbonic acid is expelled by lunar volcanoes it must cling to the Moon with great tenacity because of its weight. Since it is the food of plant life, it may possibly support vegetation on the Moon. Professor Pickering sees in variable dark spots on the planet organic life resembling vegetation. He figures that since certain lichens grow in certain regions of the Earth where the temperature never rises above the freezing point, there is no reason why that vegetation may not flourish on the Moon's surface.

CHAPTER XV

MARS

MARS is another instance of a celestial body whose discovery long antedates written history, for which reason it is natural to assume that its appearance in the heavens and its motions have always been known to mankind. Its ruddy light naturally associated it in the Greek mind with the God of War, just as the soft, warm glow of Venus was considered appropriate to the Goddess of Love. To the Chaldean and to other ancient star-gazers the motions of the planet were indeed of interest. No planet has received greater attention from astronomers or has been used more for the solution of important astronomical and cosmical problems.

Thus it was from an observation of the passage of the Moon in front of Mars, or what is termed by astronomers an occultation of the planet, that Aristotle concluded that the planets are more distant than the Sun and Moon. What reason he had for including the Sun it is difficult to conceive, as an occultation by that body would be quite impossible. Later it was from the study of the motions of the planet made for Tycho Brahe that Kepler was able to derive his great laws of planetary motion. By observing the great "Hour-glass Sea," or Syrtis Major, on Mars, Huygens in 1659 noted the rotation of the planet on its axis, and from a measurement of the planet made at its opposition Richer was able to obtain a reasonably accurate estimate of the distance of the Sun in 1673.

In 1783 Herschel had written: "The analogy between Mars and the Earth is perhaps by far the greatest in the whole solar system." For over a century the development of this analogy has been one of the most important features of astronomy, especially in popular estimation. To-day, with a wealth of scientific and observational data acquired during the last score of years, the question, altho more fully and intelligently discussed, is as far from solution as ever.

Mars revolves around the Sun in an orbit whose mean distance is 141,500,000 miles. But this orbit is so eccentric, amounting to 0.093, that the distance varies about thirteen million miles. As this distance from the Sun is about one-half as far again as that of the Earth, the light and heat that Mars receives are only about 4/9 of the light and heat received by the Earth, an important consideration in discussing the possibility of life on its surface.

The real diameter of Mars is about 4,200 miles, a figure correct within 20 miles, so that its surface is 23/100 and its volume 0.147 or 1/7 that of the Earth. The mass of the planet, derived from observations of its satellites, is about 1/9.4 that of the Earth, so that its density is 0.73 and the attraction of gravity on its surface 0.38 that of the Earth. Mars reflects 0.26 of the light that it receives, which is just double that of Mercury.

In Mars may be seen a striking difference between the superior and inferior planets, for the crescent phases of the latter are conspicuously absent. This is because the orbits of Mars and the other superior planets lie outside of the Earth. Consequently such a planet never comes between the Earth and the Sun. At quadrature a certain amount of the unilluminated portion is turned toward the Earth so that the planet appears like a Moon three or four days from full, with a distinctly gibbous appearance.

Kepler suspected the existence of satellites from a somewhat cryptic utterance of Galileo's in regard to the triple Saturn. No particularly sound reasons were advanced for the existence of such satellites. Still that they might be found is forcibly reflected in eighteenth-century literature. In "Gulliver's Travels" (1726) is the striking statement that an astronomer on the floating island of Laputa had discovered two tiny satellites of Mars. Dean Swift even advanced the extraordinary statement that one of these moons revolved around the planet in 10 hours, the approximate correctness of which will presently be apparent. Furthermore, Voltaire in his "Micromégas," published in 1752 and obviously modeled on "Gulliver's Travels," also speaks of these small bodies. Altho literature and imagination had preceded observation, astronomers could not detect any companions to the ruddy planet until August 11, 1877, when Professor Asaph Hall, using the 26-inch refractor of the U. S. Naval Observatory at Washington, which at the time of its construction (1873) was the largest telescope in the world, studied the vicinity of Mars with unusual care. In 1877 it was at conjunction, so that conditions were favorable for an exhaustive inquiry. On August 11 Professor Hall detected a minute speck of light near the planet, and a few days later, August 16, he ascertained positively that it was a satellite. On the following evening a second body was discovered, bewilderingly rapid in its motion. Since that time the two satellites have been frequently observed at opposition even with much smaller instruments. On July 18, 1888, the large Lick telescope was able to reveal them when their brightness was only about one-eighth that at the time of their discovery.

The names appropriately assigned to the new satellites, Deimos and Phobos (Fear and Panic), were taken from the Iliad and represent the companions in battle of the God of War. The satellites are very

all, having diameters respectively of six and seven miles, as photo-:trically measured by Professor Pickering at Harvard University, ɔn after their discovery. Phobos, the inner, is the larger, and .verses an elliptical orbit in 7 h. 39 m. 22 s. at a distance of only '60 miles. Deimos, its companion, moves in a nearly circular orbit 30 h. 18 m. at a distance from the planet of 12,500 miles.

It should be remembered in all discussions of the nature of the sur-:e of the planet Mars and in developing theories based thereon that tronomers must deal with a little disk which once in fifteen years s a maximum of about 1/5,000 the area of the full Moon. When arest the Earth Mars is at a distance of 35,500,000 miles and when served with a telescope magnifying 1,000 times it appears only as :ge as the Moon with an ordinary field glass, enlarging six or ven times. In other words, Mars is brought to a distance of 35,500 les. Hence it is difficult to distinguish minute details. Conse-.ently visual and photographic observation of Mars must be of the ɔst refined character, for especially in the former there is oppor-nity for psychological or subjective phenomena to occur in connec-ɔn with the observation. While it is neither rational nor scientific deny what credible observers claim they have seen through the lescope in examining the planet, yet it must be recognized that sual observations are attended by necessary limitations and should : received in a spirit of caution rather than of enthusiasm.

The mapping of Mars is no recent matter, for even in 1659 a rough :etch of the surface of the planet was made by Huygens in which e V-shaped marking at the equator pointing to the north can be entified as the Syrtis Major. This was followed by rough sketches 'om time to time down to 1840, when Maedler first began a sys-matic charting of the planet. His map was followed in 1864 by aiser's, by Flammarion's in 1876 and Green's in 1877. Drawings : various parts of the planet were made during these intervals, but ere not combined into good charts.

Observations made by Professor Lowell and his staff at the ob-:rvatory at Flagstaff, Arizona, have had the study of this planet ;pecially in view. The Lowell observatory itself is situated 7,300 :et above the sea and contains an excellent 24-inch telescope with hich it is claimed that the faintest stars shown on the chart made : the Lick Observatory with a 36-inch instrument are perfectly isible. The atmosphere is well adapted for telescopic work, so that 'rofessor Lowell and his colleagues possess singular advantages over ther observers. On the other hand, in many important respects there as been a lack of corroboration of their observations.

The surface of Mars, as seen in the telescope, is composed of two 'hite polar caps, which wane with the approach of summer; orange reas, which are supposed by Lowell and his followers to be deserts,

and blue-green areas, which change their hue to orange during the Martian autumn and winter and reassume their verdant tint in spring. The planet is covered with a network of fine lines, first discovered by Schiaparelli in 1877 and called by him "canals," a designation by which they are still known. These canals connect the polar caps with the temperate and equatorial zones. According to Professor Lowell, they may be regarded as planetary irrigation ditches which serve the purpose of leading the melting water of the poles to those desert regions which would still blossom if properly watered. The canals disappear with the approach of winter and creep down from the poles toward the equator in summer, a phenomenon which long puzzled astronomers until Pickering ingeniously suggested that we see not the canals themselves (for they are much too narrow), but the vegetation which fringes their banks, which withers as the cold of winter descends and which flourishes with the melting of the snows.

It was Schiaparelli who also first announced the curious doubling of the canals in certain instances, an announcement which was at first received with derision but which has since been confirmed by his disciple, Lowell, and the astronomers of the great observatories. This curious gemmation has not been satisfactorily explained, altho Professor Lowell attributes it in part to vegetal causes. By opponents of his theory the doubling is regarded as an optical illusion, which can hardly be the case, because all and not certain of the canals would exhibit the phenomenon. Furthermore, there is some photographic evidence offered by Mr. Lampland, of Professor Lowell's staff, that both the canals and their doubling are real.

The visual observations of Professor Lowell have been undertaken with great thoroness and have brought to light much material which he has employed in the development of his theories. To do justice to his work in a single chapter is manifestly impossible. It will be most satisfactory to the reader to recapitulate in Professor Lowell's own words, derived from his work on "Mars and Its Canals," the fundamental facts which he has recorded and on which he bases his conclusions. They are as follows:

"(1) Mars turns on its axis in 24 h. 37 m. 22.65 s. with reference to the stars and in 24 h. 39 m. 35 s. (as a mean) with regard to the Sun. Its day therefore is only about forty minutes longer than ours.

"(2) Its axis is tilted to the plane of its orbit by about 23° 59′ (most recent determination, 1905). This gives the planet seasons almost the counterpart of our own in character, but in length nearly double ours, for

"(3) Its year consists of 687 of our days, 669 of its own.

"(4) Polar caps are plainly visible which melt in the Martian summer to form again in the Martian winter, thus implying the presence of a substance deposited by cold.

"(5) As the polar caps melt they are bordered by a blue belt, which retreats with them. This excludes the possibility of their being formed of carbon dioxide and shows that of all the substances we know the material composing them must be water.

"(6) In the case of the southern cap, the blue belt has widenings in it in places. These occur when the blue-green areas bordering upon the polar cap are largest.

"(7) The extensive shrinkage of the polar snows shows their quality to be inconsiderable and points to scanty deposition due to dearth of water.

"(8) The melting takes places locally after the same general order and method, Martian year after year, both in the south cap

"(9) And in the north one. This is evidenced by the recurrence of rifts in the same places annually in each. The water thus let loose can, therefore, be locally counted on.

"(10) That the south polar cap is given to greater extremes than the north one implies again, in view of the eccentricity of the orbit and the tilt of the axis, that deposition in both caps is light.

"(11) The polar seas at the edges of the caps being temporary affairs, the water from them must be fresh.

"(12) The melting of the caps on the one hand and their re-forming on the other affirm the presence of water vapor in the Martian atmosphere, of whatever else that air consist.

"(13) Since water vapor is present, of which the molecular weight is 18, it follows from the kinetic theory of gases that nitrogen, oxygen and carbonic acid, of molecular weights 28, 32 and 38 respectively, are probably there, too, owing to being heavier.

"(14) The limb-light bears testimony to this atmosphere.

"(15) The plant's low albedo points to a density for the atmosphere very much less than our own.

"(16) The apparent evidence of a twilight goes to affirm this.

"(17) Permanent markings show upon the disk, proving that the surface itself is visible.

"(18) Outside of the polar cap the surface is divided into red-ocher and blue-green regions. The red-ocher stretches have the same appearance as our deserts seen from afar,

"(19) And behave as such, being but little affected by change.

"(20) The blue-green areas were once thought to be seas. But they cannot be such because they change in tint, according to the Martian season, and the area and the amount of the lightening is not offset at the time by corresponding darkening elsewhere

"(21) Nor by any augmentation of the other polar cap or precipitation into cloud. It cannot, therefore, be due to shift of substance.

"(22) Furthermore, they are all seamed by lines and spots darker

than themselves, which are permanent in place, so that there can be no bodies of water on the planet.

"(23) On the other hand, their color, blue-green, is that of vegetation. This regularly fades out, as vegetation would, to ocher for the most part, but in places changes to a chocolate-brown.

"(24) The change that comes over them is seasonal in period, as that of vegetation would be.

"(25) Each hemisphere undergoes this metamorphosis in turn.

"(26) That it is recurrent is again proof positive of an atmosphere.

"(27) The changes are metabolic, since those in one direction are later reversed to a restoration of the original status. Anabolic as well as katabolic processes thus go on there—that is, growth as well as decay takes place. This proves them of vegetal origin.

"(28) The existence of vegetation shows that carbonic acid, oxygen and undoubtedly nitrogen are present in the Martian atmosphere, since plants give out oxygen and take in carbonic acid.

"(29) The changes in the dark areas follow upon the melting of the polar caps, not occurring until after that melting is under away,

"(30) And not immediately then, but only after the lapse of a certain time.

"(31) Tho not seas now, from their look the dark areas suggest old sea bottoms, and when on the terminator appear as depressions, (whether because really at a lower level or because of less illumination is not certain).

"(32) That they are now the parts of the planet to support vegetation hints the same past office, as water would naturally drain into them. That such a metamorphosis should occur with planetary aging is in keeping with the kinetic theory of gases.

"(33) Terminator observations prove conclusively that thre are no mountains on Mars, but that the surface is surprisingly flat.

"(34) But they do reveal clouds which are usually rare and are often, if not always, dust-storms.

"(35) White spots are occasionally visible, lasting unchanged for weeks in the tropic and temperate regions, showing the climate is apparently cold,

"(36) But at the same time proving that most of the surface has a temperature above the freezing-point.

"(37) In winter the temperate zones are more or less covered by a whitish veil, which may be hoar-frost or may be cloud.

"(38) A spring haze surrounds the north polar cap during the weeks that follow its most extensive melting.

"(39) Otherwise the Martian sky is perfectly clear, like that of a dry and desert land."

These facts, according to Professor Lowell, make reasonably evident on Mars the presence of—

"(1) Days and seasons substantially like our own.

"(2) An atmosphere containing water vapor, carbonic acid and oxygen.

"(3) Water in great scarcity.

"(4) A temperature colder than ours, but above the Fahrenheit freezing-point, except in winter and in the extreme polar regions.

"(5) Vegetation."

While all of Professor Lowell's observations and results are not accepted by all astronomers, and there is considerable opposition to his conclusions, nevertheless they are of interest and worth stating as representing this aspect of the matter in his own words. Comparative studies of lunar and Martian spectra made on the summit of Mt. Whitney in September, 1909, by Campbell of the Lick Observatory seem to preclude the possibility of much water on Mars. Campbell's photographs show that the Martian atmosphere is no richer in water than the Moon's, which if true summarily disposes of Martian life. Slipher of Lowell's staff claims to have obtained ample spectroscopic evidence of water. The following paragraphs, taken from the concluding chapter of Lowell's book on "Mars and Its Canals," may be said fairly to sum up his views on Martian life:

"That Mars is inhabited by beings of some sort or other we may consider as certain as it is uncertain what those beings may be. The theory of the existence of intelligent life on Mars may be likened to the atomic theory in chemistry, in that in both we are led to the belief in units which we are alike unable to define. Both theories explain the facts in their respective fields and are the only theories that do, while as to what an atom may resemble we know as little as what a Martian may be like. But the behavior of chemic compounds points to the existence of atoms too small for us to see, and in the same way the aspect and behavior of the Martian markings implies the action of agents too far away to be made out.

"One of the things that makes Mars of such transcendent interest to man is the foresight it affords of the course earthly revolution is to pursue. On our own world we are able to study only our present and our past; in Mars we are able to glimpse, in some sort, our future. Different as the course of life on the two planets undoubtedly has been, the one helps however imperfectly, to better understanding of the other."

The views expressed by Professor Lowell in the work just quoted were further developed by him in the course of a few years succeeding its publication, and in "Mars as the Abode of Life," published in 1908, he expresses himself as even more firmly convinced that Mars is inhabited by a race of intelligent beings. Additional study of Martian phenomena, according to Professor Lowell, indicates that the

canals and oases as he sees them are proof that life of no mean order of intelligence prevails on the planet. He suggests:

"Part and parcel of this information is the order of intelligence involved in the beings thus disclosed. Peculiarly impressive is the thought that life on another world should thus have made its presence known by its exercise of mind. That intelligence should thus mutely communicate its existence to us across the far stretches of space, itself remaining hid, appeals to all that is highest and most far-reaching in man himself. More satisfactory than strange this, for in no other way could the habitation of the planet have been revealed. It simply shows again the supremacy of mind. Men live after they are dead by what they have written while they are alive, and the inhabitants of a planet tell of themselves across space as do individuals athwart time by the same imprinting of their mind."

To this he adds the statement that conditions for life on the planet are approaching an end, as it is drying up, and the energies of the inhabitants are given to conserving the slowly diminishing supply of water. "The drying up of the planet is certain to proceed until its surface can support no life at all." So that, as compared with the Earth, Mars presents a distinctly later period of evolution. No such danger at present confronts our own planet. But assuming that these explanations are correct, it is not improbable that the coöperative action of all the nations of the world may be required at some future date to deal with a similar problem.

In opposing the idea of canals on the surface of Mars, much stress has been laid on the alleged fact that the finer markings and some of the apparent doublings are based upon optical illusions or psychological phenomena. Thus, to prove that instinctively the eye would arrange in the form of straight lines vague suggestions of markings, E. W. Maunder, of the Greenwich Observatory, England, and J. E. Evans, of the Royal Hospital School at Greenwich, in 1902 performed an experiment with a number of schoolboys. A circular disk was exhibited five or six inches in diameter, on which was represented with some accuracy the shaded area of the planet as it might appear in the telescope. Instead of canals, a few faint, wavy lines and a larger number of faint dots were inserted promiscuously. The boys were told to fill in with pencil on small circles on sheets of paper the details of the object exhibited to them, exercising as much care as possible. The object of the experiment was not communicated to the boys. None of them had any idea of the nature of the planet's surface. The result was that boys at the greatest distance from the object where the faint lines and dots were just beyond the limits of separate visibility, drew canals strikingly like those noted by the telescopic observers of the planet. Hence it was supposed that the eye in some way integrated such faint stimuli as irregular scattered dots and

faint, wavy lines into straight lines which have no objective existence. Much has been made of this test, but it may hardly be called conclusive, for Flammarion when repeating the experiment with French boys was unable to secure in their sketches lines resembling canals. Moreover, photographs taken during the opposition of 1905 at Flagstaff bring out a large number of the more prominent canals as straight lines.

It is possible that psychology plays an important part, and Professor Andrew Ellicott Douglass, of the University of Arizona, who has had opportunities to observe the planet at several favorable oppositions, believes that the subjective phenomena have much to do with Martian observations. He says:

"One may confidently say that such realities do exist. But with the very faint canals whose numbers reach occasionally well into the hundreds, discordance reigns supreme, and it is frequently found that different drawings by the same artist antagonize each other across the page.

"Considerations along these lines led me to study seriously the origin of these inconsistent faint canals by the methods of experimental psychology, and the application of these methods has resulted in a new optical illusion and new adaptations of old and well-known phenomena." The most important of these phenomena was the halo effect where secondary images are produced under unusual conditions, which images affect the minute details of the surface. Professor Douglass also found that the irregular refraction of the eye produced apparent rays as from a small spot, which could be obviated in part by changing the position of the observer's head. "The ray illusion," he says, "is to me a very satisfactory explanation of many faint canals radiating from those small spots on Mars called 'lakes' or 'oases.' The only objective reality in such cases is the spot from which they start."

Referring again to the halo he reaches the conclusion that—

"The halo with its light area and secondary image accounts for details which have no objective reality, such as bright limbs of definite width, canals paralleling the limb or dark areas, numerous light margins along dark areas and light areas in the midst of dark, abundantly exemplified in Schiaparelli's map of 1881-82."

Professor Lowell, it must be said, has the unique advantage, or misfortune it may be, to see canal-like markings that are not visible to other astronomers. Thus on Venus he saw bands or lines which he considered bore a superficial resemblance to the canals of Mars and were apparently permanent and not due to clouds. Again he claims to have seen lines resembling canals on the third satellite of Jupiter, which others have failed to recognize. Hence many astronomers believe that he is predisposed to see such phenomena. Furthermore,

canal-like appearances have been noted on the surface of the Moon by Professor W. H. Pickering as radiating from the central peaks of the northwestern slopes of the central mountain range of the crater of Eratosthenes. He observed two canals which in a small telescope appear straight, yet, when seen with a large glass, present considerable irregularity of structure. Other and new branches or canals were also seen. In various parts of the same crater, but especially in the southeastern and northern portions, numerous small canals and lakes present themselves. These markings are practically identical in appearance with those seen upon the planet Mars. They are too small to be well shown on photographs and seem to be of much more regular structure than the larger markings, which are also called canals. It is possible that this difference is due merely to the fact that the larger markings are better seen. There can be no free water on the Moon's surface; hence any canals with flowing water are quite out of the question. Yet the appearance is vouched for as remarkably similar to that on Mars by an observer who knows the surfaces of both bodies.

CHAPTER XVI

JUPITER

As Jupiter comes next to Venus in point of brilliancy of the heavenly bodies it is but natural that it should have been known to the ancients from a remote antiquity and that its discovery of early observation should be lost in a far distant past. The brightness of Jupiter varies with its position, and the relative brightness of the planet at an average conjunction at the nearest and most remote oppositions is respectively as the numbers 10, 27, and 18.

The orbit of the planet is but slightly inclined to the ecliptic, or 1° 19′, and the planet itself moves with an orbital velocity of about eight miles a second in the sidereal period of 11.86 years, which is the time of its revolution around the Sun from a star to the same star again, as seen from the Sun. The mean distance of the orbit of the planet from the Sun is 483,000,000 miles. The eccentricity is nearly one-twentieth, the greatest and least distances from the Sun being 204,000,000 and 462,000,000 miles respectively. The average distance of the planet from the Earth at opposition is 390,000,000 miles, while at conjunction it is 576,000,000 miles. The minimum opposition distance, occurring about October 6, amounts to 369,000,000 miles, while at aphelion in April the distance is greater by about 42,000,000 miles.

Jupiter is larger than all the rest of the planets in the solar system, whether its bulk or its mass be taken into consideration. Its surface is 119 times and its volume 1,300 times that of the Earth. The mean diameter is 86,500 miles, or about eleven times that of the Earth. But if the relative masses and volumes of the two planets be compared, it will be found that Jupiter has a density less than one-quarter that of the Earth, or .24, and almost the same as that of the Sun. A body on Jupiter would weigh 2⅝ times as much as upon the surface of the Earth, because the mean superficial gravity of the planet is 2.65 times as great. Owing to its rapid rotations and its elliptical shape the difference between the force of gravity at the equator and the pole is much greater and amounts to 1/5 of the equatorial gravity, where on the Earth it is as 1/190.

The planet is brightest, as is also Saturn, in the center of the disk, which it will be recalled is the case with the Sun, but not with

Mars, Venus and Mercury. On account of this resemblance to the Sun, the idea has ben suggested that the planet may be, to some extent, self-luminous.

The planet receives too small an amount of heat from the Sun to account for the rapid changes which beyond question are taking place on its visible surface. Consequently, to produce these changes the heat must come from the planet itself. Probably the body is at a temperature little below that of incandescence, not having solidified to any appreciable extent.

The most striking feature of Jupiter is its system of bright satellites, four of which were the first fruits of astronomical discovery as it is now understood, and were revealed to Galileo when he directed his small telescope toward the planet. In fact, this historic observation of January 7, 1610, meant much to astronomy. When the great Italian scientist determined the periods of these strange bodies, or "Medicean stars," as he termed them, a new era was opened in astronomy. The four satellites, in addition to being numbered in the order of their distance from the planet, are also known by the mythological names of Io, Europa, Ganymede and Callisto, and revolve in sidereal periods, ranging from 1 day, 18½ hours to 16 days, 16½ hours at relative distances of between 262,000 and 1,169,000 miles. From the small telescope of Galileo in the opening years of the seventeenth century to the Lick refractor at the close of the nineteenth is indeed a far cry, but the four satellites of Jupiter remained alone until a fifth was added to their number by Professor E. E. Barnard at Mt. Hamilton in September, 1892. This discovery was as much a triumph for the modern telescope as the original detection of the four moons was an achievement for the "Optick Tube," for the satellite is visible only with telescopes having a greater aperture than 18 or 20 inches. It has a period of 11 hours, 57.4 minutes, and its nearness to the planet, 112,500 miles, makes it additionally difficult to see.

But this was by no means the end, for where the eye failed the photographic plate was available. In December, 1904, and January, 1905, Professor C. D. Perrine of Lick Observatory added, by photography, two new moons to Jupiter's system. Both of these bodies revolve at a greater distance than the older known satellites. Still more recently, P. Melotte of Greenwich Observatory, while examining a photograph made there on February 28, 1908, found a faint object which proved to be an eighth satellite of Jupiter, photographed several times at Greenwich, at Heidelberg and at Lick Observatory. The movement is retrograde, which anomaly is of vast cosmical importance. Photography also added a ninth satellite found by Dr. Nicholson at the Lick Observatory, in July, 1914.

The discovery of the satellites of Jupiter by Galileo was still an-

other point which brought him in conflict with the Church. In 1611 there was published a tract in which it was mentioned that the satellites of Jupiter were unscriptural.

Galileo believed that it was possible to determine the longitude at sea by means of the satellites of Jupiter, and corresponded with the Spanish Court in reference to a method which he had devised. He held that if the movements of Jupiter's satellites and, in particular, the eclipses which constantly occur when the satellites pass into Jupiter's shadow, could be predicted, then a table could be prepared giving the dates at some standard place, say Rome, at which the eclipses would occur. The local time of the eclipse could be readily observed and referred to the local time—that is, its noon or when the Sun is highest in the sky, with no great amount of error, and the difference in time between the two places would naturally give the difference in longitude.

In Galileo's day astronomers and navigators had no accurate means of keeping time, such as the modern chronometer, which, carried on a ship, can be kept at Greenwich or some other standard time and give the difference between that and local time immediately. Galileo knew nothing of the pendulum clock of Huygens, or, more especially, the chronometer of John Harrison (1693-1776), which has made possible the accurate determination of longitude at sea. The motions of the satellites continued to arouse general interest, and Kepler, taking the movements of the four satellites around the parent planet, as recorded by Galileo and Simon Marius, found that his laws of planetary motion applied to the satellites as well as to the planets themselves.

But perhaps the most striking of the discoveries made with Jupiter, after the actual detection of its satellites, was that of the Danish astronomer, Olaus Roemer (1644-1710), in 1675, when engaged in the study of the motion of Jupiter's satellites. He ascertained that the intervals between successive eclipses of a moon, which were caused by its passage into Jupiter's shadow, were regularly less when Jupiter and the Earth were approaching each other than when they were receding. Accordingly he made the ingenious assumption that light travels through space, not instantaneously, but at a certain definite tho very great speed. Accordingly, if Jupiter is approaching the Earth, the time which the light from one of his moons takes to reach this planet must be gradually decreasing, and consequently there is less interval between successive eclipses as seen from the Earth than when the great planet is departing from it. Now the difference of the intervals thus observed, together with the known rates of motion of Jupiter and of the Earth, which, of course, could be calculated, made it possible to form a rough estimate of the speed at which light travels. Roemer had not sufficient observations at his

command to investigate this problem very thoroly, but he was able to compute the apparent retardation of the eclipses between opposition and conjunction and thus to obtain a value for twice the time required for light to come from the Sun to the Earth, which time was very nearly 500 seconds, or eight minutes and twenty seconds. This was the first work on the so-called "equation of light." It was many years before astronomers accepted Roemer's really wonderful method for obtaining the distance from the Sun. To-day the process is reversed. By elaborate physical experiments made on the Earth's surface it is possible to obtain an accurate value for the velocity of light and then by means of the light equation to deduce the distance from the Sun.

James Bradley (1693-1762), the third Astronomer Royal of Great Britain, also devoted himself to the study of the satellites of Jupiter. With Cassini's observations, which he used as the basis for some tables, as well as many of his own dealing with the eclipses of the satellites, he noted a large number of discrepancies between the observations and the tables, and found even more peculiarities in their motions than did the early observers. Using Roemer's suggestion of the finite time consumed by light in traveling from Jupiter to the Earth, which Cassini and other astronomers of his time had rejected, Bradley was able to make a series of new and valuable tables of Jupiter's satellites, which were printed in 1719 in Halley's "Planetary and Lunar Tables." Bradley's knowledge of the satellites of the planet was applied to the method of the determination of longitude suggested by Galileo, and with great accuracy he found the longitudes of Lisbon and of New York.

Jupiter rotates on its axis, which is inclined about 3° to the orbit, once in about 9 hours and 55 minutes, a time which is difficult to obtain more than approximately, for when different spots are observed different results are obtained. These spots were first observed in 1665 by Giovanni Domenico Cassini (1625-1712), who was also the first to study the so-called belts. He was able to report the discovery of the rotation of the planet by watching the movement of the spots when observed through the telescope. One of these spots is the famous "great red spot" first observed in modern times by Professor C. W. Pritchett in Glasgow, Missouri, in July, 1878.

This is a rosy cloud attached to the whitish zone beneath the dark southern equatorial band. Of enormous size, measuring some 30,000 miles in longitude and somewhat less than 7,000 miles in latitude, it was seen by several observers in Europe in the year of its discovery, and in the following year was observed by almost every astronomer possessed of a telescope. For three years the red spot was conspicuous. Then it began to fade. When the planet returned to opposition in 1882 and 1883 Rica's observations of it at Palermo, May 31,

1883, were expected to be the last. It began to recover, however, toward the end of the year, and at the beginning of 1886, according to W. F. Denning, an English observer, had much the same aspect as in October, 1882.

Before the "great red spot" astronomers had noticed various markings on the planet, one of which, as we have seen, was recorded by Cassini in 1665 as having a rotation period of 9 hours and 56 minutes. This spot reappeared and vanished eight times within the next forty-three years and was last seen by Maralda in 1713. It was, however, very much smaller than the recent object and showed no unusual color. Agnes M. Clerke, from whose "History of Astronomy" is abstracted this brief description of the "great red spot," further discusses the phenomenon as follows: "The assiduous observations made on the 'Great Red Spot' by Mr. Denning at Bristol and by Professor Hough at Chicago afforded ground only for negative conclusions as to its nature. It certainly did not represent the outpourings of a Jovian volcano; it was in no sense attached to the Jovian soil—if the phrase have any application to that planet; it was not a mere disclosure of a glowing mass elsewhere seethed over by rolling vapors. It was, indeed, certainly not self-luminous, a satellite projected upon it in transit having been seen to show as bright as upon the dusky equatorial bands.

"A fundamental objection to all three hypotheses is that the rotation of the spot was variable. It did not then ride at anchor, but floated free. Some held that its surface was depressed below the average cloud level and that the cavity was filled with vapors. Professor Wilson, on the other hand, observing with the 16-inch equatorial of the Goodsell Observatory in Minnesota, received a persistent impression of the object's 'being at a higher level than the other markings.'

"A crucial experiment on this point was proposed by Mr. Stanley Williams in 1890. A dark spot moving faster along the same parallel was timed to overtake the red spot toward the end of July. An unique opportunity hence appeared to be at hand for determining the relative vertical depths of the two formations, one of which must inevitably, it was thought, pass above the other. No forecast included a third alternative, which was nevertheless adopted by the dark spot. It evaded the obstacle in its path by skirting around the southern edge.

"Nothing, then, was gained by the conjunction beyond an additional proof of the singular repellent influence exerted by the red spot over the markings in its vicinity. It has for example, gradually carved out a deep bay for its accommodation in the gray belt just north of it. The effect was not at first steadily present. A premonitory excavation was drawn by Schwabe at Dessau, September

5, 1831, and again by Trouvelot, Barnard and Elvins in 1879; yet there was no sign of it in the following year.

"Its development can be traced in Dr. Beddicker's beautiful delineations of Jupiter, made with the Parsontown 3-foot reflector, from 1881 to 1886. They record the belt as straight in 1881, but as strongly indented from January, 1883; and the cavity now promises to outlast the spot. So long as it survives, however, the forces at work in the spot can have lost little of their activity. For it must be remembered that the belt has a shorter rotation-period than the red spot, which accordingly (as Mr. Elvins of Toronto has pointed out), breasts and diverts, by its interior energy, a current of flowing matter, ever ready to fill up its natural bed and override the barrier of obstruction."

In 1910 and 1911 the "red spot" increased in brilliancy, fading in 1913, 1914 and 1915, yet, as Prof. Barnard wrote in a letter "I saw it a few nights ago." Its visibility is within the range of the amateur.

Besides the spots, Jupiter exhibits curious belts or bands. Herschel, that observer "par excellence," frequently turned his telescope to Jupiter as to other planets, and became greatly interested in its bright bands. In 1793 he was the first to interpret these as bands of clouds. In fact, telescopic examination of Jupiter during the nineteenth century established the fact that the visible surface of the planet appears as layers of clouds, and its low density, 1.3, as compared with water, 1, and the Earth, 5.5, together with the rapid changes, indicates that the planet is, to a great extent, in a fluid condition, and that there is a high temperature at a very moderate distance below the visible surface.

CHAPTER XVII

SATURN

The planet Saturn was considered by the ancients to be the most distant of the moving heavenly bodies, a position it retained even after the triumph of the Copernican ideas and the establishment of the modern conception of the solar system. The reason for this was that the period of its oscillatory motion to and fro in the heavens was longest of all the planets. The ancients noted that it took 29½ years for Saturn to return to the same place among the stars, as compared with 12 years for Jupiter, and correspondingly less for the other planets down to 88 days for Mercury. Accordingly they considered that Saturn was the most distant.

Eudoxus (409 B.C. [?]-356 B.C. [?]), as has been shown, believed that the motion of Saturn, as in the case of Mars and Jupiter, could be represented roughly by supposing that each planet oscillated to and fro on each side of a fictitious planet which moved uniformly around the celestial sphere in or near the ecliptic. The slow period of Saturn also made it the most distant of the planets in the system as devised by Copernicus, who computed its distance from the Sun as nine times that of the Earth, which may be compared to his credit with the modern figure of 9½ times.

After the development of observational astronomy Tycho Brahe in 1563 made his first recorded observation at the University of Leipzig, noting the close approach of Jupiter and Saturn, which he found was quite a month in error in the prediction of the Alfonsine Tables, published in Spain in 1252 and in general use by astronomers throughout Europe. The next important observation of Saturn was indeed of epoch-making significance in astronomy. With his new telescope it was but natural that Galileo should examine Saturn as he did the other planets. Turning his telescope toward Saturn he observed that that planet, too, was not single and complete, but apparently consisted of three parts, or, as it appeared in a drawing made at the time by him, of a central body and two satellites in close proximity, which naturally seemed to resemble those of Jupiter. At subsequent observations he failed to see more than the central and larger portion, and, consequently, completely baffled, he left the problem as a legacy to his successors.

The two appendages were seen and described under varying conditions by a number of astronomers, but the true solution was first

furnished by Huygens (1629-1695), when he studied with one of his powerful telescopes the appearance of the planet. Huygens announced in 1655 that he had discovered a single satellite, which he named Titan. With a still more powerful instrument he found that the effect of two component bodies observed by Gallileo was due to the fine ring which surrounded the planet and was inclined at a considerable angle to the plane of the ecliptic and consequently to the plane in which Saturn proceeds around the Sun. As the ring was extremely fine it became invisible, either when its area was directly opposite to the observer or when it was directed toward the Sun, as in that case it received no light for reflection. Near this opposition or invisibility the ring appears to be foreshortened and presents the appearance of two arms projecting from the body of the planet. The ring, of course, gradually widens from its opposition or invisibility and the opening becomes visible, a period of seven years elapsing between such a state and when the ring is seen at its widest.

With the observations of Huygens the reasons for Galileo's varied observations were furnished. To make the matter more conclusive Huygens collected and published a series of early drawings by various observers, which drawings he compared with his own observations. Thus what Galileo conceived as two satellites was really the ring when seen with its greatest breadth. The disappearance of these satellites occurred when the edge of the ring was presented to his view, the revolution of the planet giving to an observer on the Earth a series of phases in which the appearance of the planet is remarkably different.

What Huygens saw is now familiar to every one who has observed Saturn through a telescope. Surrounding the central body are rings parallel to the planet's equator, but inclined about 27 degrees to the plane of its orbit and 28 degrees to the ecliptic, their nodes being at longitude 169° in Aquarius and at longitude 348° in Leo. The plane of the rings remains sensibly parallel to itself for a very long time. For fifteen years, or half a revolution of Saturn, their northern face is seen and during the remaining half of the revolution their southern face. When the Earth passes over the plane of the rings at the time of transition their edge is presented so that the ring virtually disappears from view, as occurred, for example, in 1908, and in 1612 had occasioned Galileo's perplexity. The thickness of the rings is less than 100 miles; consequently their edge was quite invisible through his feeble telescope. The disappearance of the rings recurs at intervals of about fifteen years.

In 1675 Giovanni Domenico Cassini (1625-1712) noticed a dark marking in the ring which later was found to mark the division of the ring into two distinct schemes, a narrow and outer ring, to which the name of "Cassini's Division" was given. As was natural, the pe-

between 36,000 and 37,000 miles. A model of the outer ring, constructed on the scale of 10,000 miles to the inch, could be made with an approximation to accuracy from a sheet of writing paper nearly seventeen inches in diameter.

Cassini's discovery of the dark markings in Saturn's ring was one result of a series of telescopic observations which he made of the planet, in which he discovered four new satellites—Japetus in 1671, Rhea in 1672, and Dione and Thetis in 1684. This list of satellites was increased by two more in 1789, when Herschel, using his 40-foot telescope for the first time, August 28th, detected a sixth satellite of Saturn, Enceladus, and on September 17th discovered a fainter satellite, Mimas. Both of these were nearer to the planet than any of the five previously observed. In September, 1848, W. C. Bond, of Cambridge, Mass., discovered Hyperion, and two days later this same satellite was also observed at Liverpool by William Lassell.

A ninth satellite of Saturn, Phœbe, was discovered by Professor W. H. Pickering on photographic plates taken at the Harvard Observatory at Arequipa, Peru, and was announced in July, 1904, the satellite being seen on a number of recent photographs. This satellite is much smaller than any of the existing moons; so much so, in fact, that it is beyond the visibility of the human eye with any existing telescope. It revolves around Saturn at a distance of many millions of miles, far beyond the orbit of Japetus and with a period correspondingly longer, and, strange to say, in an opposite direction from its fellows.

Professor Pickering also discovered in 1905 a tenth satellite of Saturn, Themis, which revolves much closer to the planet. It is said to be the faintest object in the solar system, and is a striking illustration of what astronomical photography can accomplish in the way of discovery.

Saturn moves in an orbit which is somewhat more eccentric than that of Jupiter, but which is at a mean distance from the Sun of 886,000,000 miles. The equatorial diameter is about 75,000 miles and the polar diameter about 68,000, giving a mean diameter of 73,000 miles, or a little more than nine times that of the Earth and a volume greater by 760 times. Yet Saturn is a very light body, having a mass only 95 times that of the Earth and a density of one-eighth, which would give it a specific gravity of five-sevenths that of our own planet.

The same arguments advanced in favor of a high temperature for Jupiter can be used with increased force in the case of Saturn. It may be assumed that a large proportion of this bulky globe is composed of heated vapors which are vigorously circulated by the process of cooling.

Professor Asaph Hall, of Washington, in 1876 made observations

of the white spot which was visible on the surface of the planet for some weeks. He established a period of rotation of 10 hours, 14 min. and 24 sec., which agrees closely with 10 hours, 16 min. determined by Herschel in 1794. Hall's value has been confirmed by other observers and is generally accepted.

Saturn shows belts similar to those of Jupiter, with a brilliant zone at the equator. The edges of the disk are not so brilliant as the central portion, for the pole of the planet is at times marked with a darkish cup of greenish color.

CHAPTER XVIII

URANUS AND NEPTUNE

The discovery of Uranus distinctly represents one of the most important results of modern methods in astronomy. The other planets considered were known from prehistoric times. Even the least conspicuous of them could be observed with the naked eye under favorable conditions. Just as the satellites of Jupiter were the first fruits of telescopic discovery in the heavens, so Uranus was the first planet to be telescopically added to the list which through centuries has been known and studied.

Its discovery was made on March 13, 1781, by Sir William Herschel while engaged in the systematic examination of every stellar body visible with his 7-foot reflecting telescope. Herschel states that: "In examining the small stars in the neighborhood of 'H. Geminorum' I perceived one that appeared visibly larger than the rest; being struck with its uncommon appearance I compared it to 'H. Geminorum' and the small star in the quartile between 'Auriga' and 'Gemini,' and finding it so much larger than either of them I suspected it to be a comet."

Though it appeared as a star of the sixth magnitude, its difference from the other stars was at once appreciated by Herschel and is evidence of that keenness of sight which was so characteristic of him. Observations of the new body and study of its orbit failed to establish it as a comet. Within three or four months of its discovery the conclusion was reached first by Anders Johann Lexell (1740-1784) that it was a new planet which revolved around the Sun in an orbit nearly circular at a distance of about nineteen times that of the Earth and nearly double that of Saturn.

Herschel's discovery at once won for him a national reputation and royal honors, which he attempted to reciprocate by conferring the name of his royal patron, George III., on the new planet, calling it Georgium Sidus. But the name never gained currency outside of England. After a vain attempt to apply Herschel's name to it, the old mythological nomenclature was observed and the new planet came permanently known as Uranus, at the suggestion of Bode, after the father of Saturn and the grandfather of Jupiter. The name means Heaven itself, beyond which it was supposed nothing further could be found.

Following its discovery by Herschel, with a reflecting telescope 40 feet in length and of 4-foot aperture, came the detection on January 11, 1787, of two moons or satellites of Uranus, to which the names of Oberon and Titania were subsequently given. Herschel discovered that these moons moved almost at right angles to the ecliptic in a direction contrary to that of all previously known members of the solar kingdom except the comets. He suspected the existence of four more such satellites, but he was not able to assure himself positively of their existence. In fact, it was only his large telescope and his keen eye that enabled the first two moons to be observed. But with the progress of astronomy and the improvement of instruments other discoveries were bound to come.

Within the paths of Oberon and Titania, Ariel and Umbriel were found, October 24, 1851, by William Lassell, a wealthy brewer, who during his life devoted himself assiduously and with great success to astronomy, especially telescopic observation. These satellites, altho not easily visible in a telescope on account of their distance, are much larger than the satellites of Mars or in fact many of the planetoids. It is estimated that their diameters are between 500 and 1,000 miles. Oberon, which is distant from the planet 365,000 miles, has a period of rotation of 13½ days; Titania, the largest and brightest, distant 273,000 miles, has a period of 8.7 days; Umbriel, distant 167,000 miles, has a period of 4.1 days; and Ariel, distant 120,000 miles, has a period of 2.5 days. These satellites all move in the
period of rotation is but approximate. Nevertheless, a period of 10
same plane, which is inclined about 98° to the plane of the planet's orbit. The satellites revolve in a retrograde direction.

The surface markings observed on Uranus by many astronomers have been vague and transitory, so that any determination of the period of rotation is but approximate. Nevertheless, a period of 10 or 12 hours has been indicated. It is stated that the plane of the equator is inclined something like 10 to 30 degrees to the plane of the orbit of the satellite. The disk of the planet shows a flattening at the poles, so that it has an elliptical section.

The appearance of Uranus to the naked eye is that of a small star of about the sixth magnitude. It was on this account that a high power telescope was required to differentiate it from the myriad other stars of this size to establish it as a planet. It is so far away that there is but little change in its position whether it is in opposition or quadrature. Measuring the disk, which appears in the telescope to be of a sea-green color, the diameter of the planet is found to be about 32,000 miles, or four times as great as that of the Earth, which would give it a volume 64 times greater. But, like the other distant planets, Uranus is composed of lighter materials, so that while 64

times as large its mass is but 15 times that of the Earth, or, in other proportion as regards volumes as does the Moon with the Earth.

The elliptical orbit in which Uranus moves at a mean distance from the Sun of nearly 1,800,000,000 miles requires 84 years for its passage, and the diameter of this orbit is 3,600,000,000 miles. The orbit is slightly less eccentric than that of Jupiter and amounts to 83,000,000 miles, while the periodic time of the planet is 84 years and its synodic period 369 days and 16 hours. It moves with an orbital velocity of 4⅓ miles per second. In the first half century after its discovery Uranus gave astronomers considerable trouble, as observations showed that it was not following exactly its computed path and that it deviated by a substantial amount. About 1830 Bessel suggested that the discrepancies in the observed and calculated orbits might be due to an unknown planet, then more distant from the Sun than Uranus, and such was found to be the case.

As Uranus was the triumph of telescopic discovery, so Neptune represents one of the greatest achievements of mathematical astronoomy. In fact, when the French astronomer, Leverrier, at Paris, wrote to Galle, at Berlin, substantially as follows, "Direct your telescope to a point on the ecliptic in the constellation of Aquarius in longitude 326° and you will find within a degree of that place a new planet looking like a star of about the ninth magnitude, and having a perceptible disk," the German astronomer, within thirty minutes after he had begun his search, on the night of September 23, 1846, was able to find the new planet but 52′ distant from the point indicated by Leverrier.

The discovery of Neptune came, as has been suggested, from discrepancies observed in the path of Uranus, which oftentimes were almost so marked as to be observed without the aid of the telescope. As an explanation of the disturbance, an unknown exterior body was suggested, which was not only plausible but so obvious that several astronomers were devising mathematical plans of campaign for its discovery.

A young graduate of Cambridge University, John Couch Adams (1819-1892), who had distinguished himself in mathematical work, assiduously addressed himself to the problem, and in 1845 sent to the Astronomer Royal at Greenwich numerical estimates of the elements and mass of the unknown planet, together with an indication of its actual place in the heavens. Unfortunately, Adams' work, for various reasons, was not taken up by the government astronomers, and in the meantime Urbain Jean Joseph Leverrier (1811-1877), as a result of the study of the stability of the solar system, and especially of the Uranian difficulty, to which his attention had been directed in 1845 by Arago, announced before the French Academy that only an exterior planet could produce the observed effects.

Such an announcement aroused astronomers to a point of expectancy, and in fact, as Sir John Herschel declared to the British Association regarding the hypothetical new planet, "We see it as Columbus saw America from the coast of Spain." In less than two weeks from the time of this utterance the message quoted was sent to Galle at Berlin. Within a week Neptune was also observed in England, where delays lost the honor of priority for Adams.

Once the existence of the new planet was established, a few weeks' observation made possible the computation of its orbit and its identification with what had been considered a fixed star.

Neptune supplied the exception which proved the rule in the case of Bode's law, discussed in the chapter on planetoids, for its mean distance from the Sun was 2,800,000,000 miles instead of 3,600,000,000 as would be required under the terms of the law. Furthermore, Neptune has an orbit with an eccentricity of only 9/1,000, so that its path is more nearly circular than that of any other member of the solar system except Mercury. But so large is its orbit that the small eccentricity makes a variation of over 50,000,000 miles in the distance of the planet from the Sun at different parts of its orbit. Moving with an orbital velocity of about 3⅓ miles a second, it requires 164 years for its journey around the Sun.

Neptune has but one satellite, which Lassell found in 1846, within a month of the original discovery of the planet. Its distance is about 221,500 miles and its period of revolution is 5 days and 21 hours. It is a small body, about 2,000 miles in diameter, or about the size of the Earth's Moon, and it moves backward just as the satellites of Uranus, in an orbit that is inclined 145° to that of the planet.

Like Uranus, Neptune varies little, as its distance is so great that any variation by change in the position of the planet would not affect its appearance on the Earth. Its diameter is estimated at about 35,000 miles, which would give a volume 85 times that of the Earth (or according to Professor T. J. J. See, U. S. N., 27,190 miles); but, as also the case with Uranus, it is much lighter than the Earth. As its density is probably about 0.20, its mass, which astronomers compute from the motion of its satellite, is about seventeen times that of the Earth. On account of its great distance it receives from the Sun about 1/906 the amount of heat that falls upon the Earth. If its capacity for absorbing and retaining heat are the same, the theoretical temperature would be about 360° F. the air (—220° C.), or between the temperature of liquid air and the air on the Earth (complex methods to produce it have to be adopted in a physical laboratory). Nevertheless, the amount of light received from the Sun by Neptume is not insignificant, and the noonday illumination of the planet would be some 700 times that of brightest moonlight. If the Sun were

placed in Neptune's orbit, its light would equal that of 687 full moons.

Observers have reported belts, as surface markings on Neptune. These are too indeterminate to enable the measurement of its rate of rotation by observation; but from various intricate processes Neptune is believed to have a slower rotation than Jupiter or Saturn.

CHAPTER XIX

THE LITTLE PLANETS

In the chapter on the Solar System it has been shown how Titius in 1772 pointed out that if 4 should be added to the following series (irregular in that the first number should be ½ instead of 0): 0, 3, 6, 12, 24, 48, a sequence of numbers would be obtained that indicated the relative distances of the six planets, with the striking exception that next after Mars there was no representative. Bode filled this gap with a hypothetical planet, and his name is often associated with that of Titius in the statement of this law.

After the discovery of Uranus by Herschel in 1781 the law of Titius or Bode, with which this planet conformed, gained considerable respect from astronomers, altho no mathematical or other reason was known to uphold the singular relation between the distances of the planets from the Sun. At any rate, the conviction that there must be an undiscovered planet between the orbits of Mars and Jupiter, as was even suspected by Kepler in his "Mysterium Cosmographicum" of 1596, was strengthened, and accordingly it was proposed by a voluntary association of astronomers in 1789 to undertake a systematic search for the missing planet. An organization was arranged on a fairly methodical basis by Baron Von Zach; but before these "celestial police," as the astronomers enlisted for this purpose were humorously termed by their organizer, had secured results from their plan of coöperation the missing planet was found under interesting and somewhat extraordinary circumstances.

At an observatory at Palermo, Sicily, Guiseppe Piazzi (1746-1826) had been at work for some nine years on the preparation of a catalogue of the stars. On January 1, 1801, he noted an eighth magnitude star, which on subsequent evenings shifted its position and induced him to believe that he had discovered a new kind of comet without tail or coma, and so he described it in a letter to Bode at Berlin. A fortnight later the wandering body changed its retrograde for direct motion, and before the observations could be repeated by other European astronomers Piazzi's moving star approached too near the Sun to be visible any longer. For its rediscovery some accurate knowledge of its path was essential.

Never before had there been such meager data on which to calcu-

late the motion of a celestial body, for even in the case of Uranus observations for almost a century had been made and recorded on the assumption that that planet was a fixed star. That the new star was a planet, however, lay outside the realm of consideration. It soon was found that the calculation of its orbit could not be adjusted, for the observations did not harmonize with any sort of parabolic cometary orbit. Then the supposition arose that it was a planet and that it had an elliptical orbit. But how was such a path to be calculated? The case had never yet arisen where a planet which had a relatively rapid motion had been under observation for so short a time and the orbital velocity of which was unknown. Men of the hour were not wanting, and a brilliant young German mathematician, Carl Friedrich Gauss (1777-1855), of Göttingen, now entered the ranks of astronomy. He computed the orbit of the new body with remarkable skill, and in November of the same year presented his conclusions to the observing astronomers. It was only on the last night of the year that the sky was sufficiently clear for good seeing. At the Gotha Observatory, almost in the very position assigned by Gauss to the runaway planet, a strange star was discovered, which filled the gap in the series of Titius, and in the following year (March, 1802), at Bremen, Dr. Heinrich Olbers (1758-1840) also observed a similar star. The first of these, at the request of Piazzi, was named Ceres, after the protecting divinity of Sicily, while the second, which furnished an additional problem for Gauss, was named Pallas. Harding, the assistant of Schröter at Lilienthal, discovered (1804) Juno as the third, and Olbers (1807) Vesta, the brightest of all the planetoids, as the fourth—all lying between the orbits of Mars and Jupiter. There were thus, in contradiction to the law of Titius, instead of one planet, four present in the zone between Mars and Jupiter. They were designated "asteroids" by Sir William Herschel, tho the more modern term "planetoids" is to be preferred.

Thus was inaugurated the discovery of minor planets, which continued during the nineteenth century and is still in progress. Where one new planet might be anticipated according to older doctrines, many were found. Various theories have been advanced to explain their existence and occurrence. That Ceres and Pallas were parts of an exploded planet was an ingenious theory which received for a time considerable acceptance, but which was disproved by Professor Newcomb. The recognition of the minor planets became of the highest importance in astronomical science, and led to the construction of star maps and to further interest in the observations of the heavens.

The discovery of the fifth planetoid did not occur for a number of years and then fell to the lot of an amateur astronomer, Postmaster Hencke, at Driessen, who was industriously searching with his telescope the quarter of the sky lying opposite the Sun. He made a

practice of mapping all the little stars and of comparing them again on the following nights. At last (1845) he found a new planetoid, to which he gave the name Astræa, and in 1847 a second, Hebe. Since then no year has passed without the discovery of one or more new planets. This may be attributed not only to the example of Hencke, with his systematic industry, but also to the perfecting of the telescope and to the publication of printed special star charts upon the basis of the localizations of numerous fixed stars. Thus by the year 1668 the number of little planets had increased to 100; in 1878, 200; 1895, 400; 1908, 800. Any further extensions are necessarily of very tiny bodies. Consequently, instead of one looked-for planet, suspected by Kepler, a complete stream is present between Mars and Jupiter.

The zeal of astronomers was directed toward the observation of the numerous newly-discovered heavenly bodies, and the most fortunate discoverers achieving success in this field were Hind (at London), Goldschmidt, an amateur (at Paris); Gasperis (at Naples), Robert Luther (at Bilk near Dusseldorf), Chacornac and the brothers Paul and Prosper Henry, who discovered at Paris, during the construction of stellar charts of the zodiac, a number of planets among the numerous charted small fixed stars; and from the United States, Watson at Ann Arbor, and C. H. F. Peters at Clinton, who astonished the world by their numerous discoveries. Johann Palisa should be named above all. While director of the observatory at Pola he discovered 83 new planets, the majority with a small telescope. Later he moved to Vienna, where large refractors were available. The number of small stars now becoming visible changed the accustomed groupings, and thus hindered rather than favored the further discovery of new planets by him. In Vienna, however, he made himself especially serviceable by following up the faint planets already discovered.

At the Lick Observatory (Mt. Hamilton, Cal.) in 1894 and 1895 Professor E. E. Barnard made a series of direct measurements of the three largest of the minor planets, obtaining for the diameter of Ceres and Vesta 405 miles for each, and for Pallas 322 miles.

The planetoids in the aggregate do not bulk very large, for we know from the calculations of the distinguished Leverrier, who studied the perturbations of Mars, that the total mass of all known or unknown bodies between Mars and Jupiter cannot exceed a fourth that of the Earth. Later knowledge derived from light observations would place the total mass of those already known at many hundred times less this limit. If the combined mess were as great as 1/100 the mass of the Earth, it would produce perturbations in Mars of which there is no evidence. B. M. Roszel in 1895 estimated that the terrestrial globe contains 3,240 times the aggregate mass of the first 311 minor planets.

In December, 1891, Max Wolff at Heidelberg began that photographic observation and discovery of the little planets, which has resulted in rich gains. Repeated and long exposures of the photographic plate are made, an equatorial telescope fitted with a camera being directed at some point in the heavens, and kept there by means of clockwork. Consequently the fixed stars register themselves upon the plate as points, and the moving planets as short faint streaks, which are discovered by means of the microscope after development and fixing. In this way more planets have been discovered in Heidelberg since 1892 than by all previous observers together. Charlois at Nice emulated Professor Wolff in applying the photographic method, so that there has developed since 1892, with great success, a new field of astronomical photography.

An American astronomer, the Rev. Joel Metcalf, at Taunton, Mass., has improved the technique of observation. In 1905 he found two and in 1906 twelve new planetoids. Since 1892 newly discovered planets have received provisional designations of the letters A, B to Z; AA, AB to AZ; BA, etc., to ZZ, and with the number of the year preceding when it has once been established that they can be observed sufficiently long to guarantee finding them again, and that they are identical with none of the earlier planets, they receive the next numeral and name, and are thus included in the system. In this manner an unnecessary increase in the lost planets of the system is avoided. In 1907 the crucial moment came in which the planet ZZ was discovered, and the series of provisional designations began again.

Up to 1896 all the 432 planetoids moved in the zone between the solar orbits of Mars and Jupiter; and, indeed, all with the same right-handed motion. Consequently no little attention was attracted when on August 13, 1898, Witt at the Urania at Berlin, photographically discovered a planet with an unusually rapid motion. The computation of its orbit showed great proximity to the Earth, and a mean solar distance of 1.46 times the distance of the Earth; hence less than that of Mars (1.52). Was this celestial body to be counted in with the stream of planetoids between Mars and Jupiter? Since the possibility existed that still other planets might be discovered which were not confined to the zone between the orbits of Mars and Jupiter, it was determined to include it with the planetoids with the numeral 433, but to distinguish it by the masculine name Eros.

The orbit of this planetoid was found to lie in that forbidden territory within the path of Mars and between it and the Earth. With the single exception of the Moon it is the nearest large heavenly body to the Earth. This little planet, hardly more than twenty miles in diameter, in addition to its anomalous position, possesses remarkable characteristics, among them an orbit of great eccentricity, which causes it to be at aphelion some 24,000,000 miles beyond the mean

distance of Mars. On the rare occasions which the planetoids come nearest to the Earth it is closer to the Earth than Mars or Venus can ever be.

Furthermore, this little planet not only is variable but varies in its variability, which has given rise to the assumption that either rapid changes are taking place on it, or its light reflecting power varies with its position as regards the Earth and Sun, as might be the case if the planetoid were really double, with two components revolving around a center of gravity, of if the body itself were unequally reflective in its various parts. The mean distance of Eros from the Sun is 135,000,000 miles, but at aphelion it is 165,000,000 miles away. Its perihelion distance is only 105,300,000 miles, or about 12,400,000 miles greater than the mean distance of the Earth. On account of the large inclination of the plane of its orbit to the plane of the ecliptic Eros never approaches the Earth nearer than about 13,500,000 miles.

These near approaches occur only when Eros is in opposition at its perihelion, which unfortunately happens rarely. Its sidereal period is 1.76 years, from which it follows that its synodic period is 2.32 years. If an opposition occurs at perihelion, then in 37 years another will occur very nearly at perihelion, for 37 is almost evenly divisible by 1.76 and 2.32. The next most favorable opposition will occur in 1931, and will furnish an unexcelled opportunity for obtaining the solar parallax.

Because of its eccentric orbit Eros acquires a highly practical significance in respect of the determination of the true size of the entire planetary system. From the laws of the orbits is found, in fact, very accurately (to six decimal places) the relations of the planetary distances. On the other hand, these distances themselves are very little known. They are inversely proportional to the solar parallax (8.80 sec.), of which one can be confident of but two decimal places. We have already seen that by means of observation of the transits of Venus, observation of the nearer planetoids and of Mars, determinations of the velocity of light and of the parallactic lunar equation, great pains were taken in the last century to ascertain with more exactness the solar parallax, and thus the extent of our entire planetary system. It appears that the observation of Eros yields this quantity with three times the exactness of the earlier methods, and that nothing else than the observation of the lunar orbit for the determination of the parallactic equation can compete with it. Thus the discovery of Eros performed a useful service for astronomy.

Two months after the discovery of Eros, Wolf, still at Heidelberg, discovered the planet Hungaria (No. 434). This, next to Eros, is, with its solar distance of 1.94 units, the innermost planet of the stream. Its orbit lies, however, entirely in the zone beyond the orbit of Mars. Just as Eros goes beyond the zone between the orbits of Mars and

Jupiter toward the inside, so three lately-discovered planets do so toward the outside; tho, to be sure, to only a small degree. These have also received masculine names.

Highly theoretical investigations have been carried out by Hansen, Glydén, Poincaré and Sir George Darwin, which have gained from orbital computation continually new points of view and have led to beautiful mathematical ideas. Here belongs the question of the simple relations of the times of revolution of a planet and of Jupiter as the most important disturbing planet, or the so-called libration of the orbit, as it comes to light in some measure with Hecuba (No. 108) and with planets of the Hecuba type. The value of the little planets is thus not to be sought upon the practical but rather upon the theoretical side.

But the trouble and time which hundreds of planets uninterruptedly required for their rediscovery and the correction of their orbits was so considerable that the question arose whether the gain was worth all the trouble. So, in the eighties of the nineteenth century, a number of astronomers demanded that a choice be made of the planets, and that only a part be followed up with accuracy, and that the rest (since indeed they apparently showed merely the same phenomena) be abandoned without attention. This would hardly have lessened the labor. For, since the discovery of planets could not be prohibited, the majority of the planets would have been lost and would be continually discovered again. Professor Tietjen at Berlin found a middle course. Since 1891 he abandoned the yearly ephemerides (tables which give the course of the planets during the entire year) and stated merely in one line, for each planet, time and place of opposition and the daily variation in its position. For selected, important and interesting little planets opposition ephemerides were printed, which gave the position of the planets daily with exactness for six weeks of their best visibility.

The majority of the planetoids appear as mere points and are immeasurably small. However, Weiss estimates, on the basis of brilliancy, the largest of them at 342 kilometers (212 miles, and the smallest at 16.14 and 10 kilometers (10 and 6.2 miles) in diameter. There is no doubt that many small bodies are in motion among them whose diameters are of 1 kilometer (3,281 feet), of perhaps 1 meter (39.37 inches) and even of 1 millimeter (0.039 inch), and that the majority on account of their faintness are not visible to Earth. The planetoids are of no immediate use to mankind. Their orbital calculations can be used neither for the determination of time nor for the guidance of mariners. But the ideal beauty of these planets is that their reappearance is continually a test of the correctness of mathematical assumptions and that they exhibit over and over again the validity of Newton's law of the universal attraction of all bodies.

CHAPTER XX

COMETS, METEORS AND METEORITES

The term "comet," derived from the Latin, coma, or hair, applied to celestial bodies which appear to have a hairy appendage, goes back to the time of the Romans. A similar word, cometa, or cometes, was used by Cicerco, Tibullus and other ancient writers. The modern astronomer speaks of the coma of a comet as distinct from the tail, and applies the term to the misty hazy light surrounding on every side a small central bright spot, which he calls the nucleus of the comet.

While the ancients distinguished between comets and meteors, or shooting stars, yet they believed them to be of the same nature, and to be found in the Earth's atmosphere not far above the clouds, or at all events much lower than the Moon. The earlier and Pythagorean view, however, was much more correct, according to modern doctrine; for it held that comets were bodies with long periods of revolution, which idea, like others attributed to Pythagoras, probably came from eastern philosophers of unknown nationality. Apollonius, the Myndian, believed that the Chaldeans were responsible for this notion of the comets; for they spoke of them as travelers that penetrated far into the upper or most distant celestial space. Similar views, typical of the imitative faculty of the Romans, says Humboldt, were held by Seneca and Pliny. The Greek philosophers in many cases preferred to disregard observations. Hence the fanciful theories of Aristotle as regards comets, as well as other astronomical matters, were prevalent for many centuries. Aristotle even believed that the Milky Way was a vast comet which continually reproduced itself.

The comet, with its brilliant head, flaming tail and uncertain appearance, could not be regarded otherwise than as a divine omen to announce some remarkable event or to forebode evil, particularly pestilence and war. Indeed, for many years the death of monarchs was believed, especially by those to whom the wish was father of the deed, to be announced by these brilliant messengers in the sky. In some cases comets were associated with misfortunes, not merely as anticipating or announcing them, but as the actual causes. Seneca's statement that "This comet was anxiously observed by every one, because of some great catastrophe which it produced as soon as it

appeared, the submersion of Bura and Helicè" referred to a very brilliant comet which appeared in 371 B.C. about the same time that these two towns of Achaia were swallowed up by the sea during an earthquake. A comet which appeared in 43 B.C. was generally believed to be the soul of Cæsar on its way to heaven. Josephus informs us that the destruction of Jerusalem was announced by several prodigies in 69 A.D., among them a sword-shaped comet which is said to have hovered over the city for the space of a year! Another classical instance may be quoted from Pliny (23-79 A.D.) in his Natural History" where he says: "A comet is ordinarily a very fearful star; it announces no small effusion of blood. We have seen an example of this during the civil commotion of Octavius." When the comet of 79 A.D. appeared, the Roman Emperor Vespasian refused to be intimidated by the frightening interpretation placed upon it. "This hairy star does not concern me," he is reported to have said; "it menaces rather the King of the Parthians, for he is hairy and I am bald." Not long after the appearance of the comet he died. No doubt the prophecies of the imperial sooth-sayer were more highly regarded thereafter.

The ancient Greeks and Romans were not the only ones who took these heavenly apparitions seriously. In France the great eclipse of 840 was said to have hastened the end of Louis le Debonaire, and it was firmly believed that the comet which appeared a year or two previously presaged this occurrence. Much of the mysticism attaching to figures found expression in the superstition that the Christian era could not possibly run into four figures. Hence the end of the world was looked for by many of the inhabitants of Europe when the year 1000 approached. So widespread was this belief that husbandry and toil were neglected. When a comet appeared the feeling was strengthened. Nothing remarkable occurred, however, beyond the natural consequences of such wholesale neglect of the proper care of the soil. Famine and pestilence in succeeding years were the result.

The comet, which, we shall see, was the famous comet of Halley that blazed forth in April, 1066, was believed to presage the success of the Norman Conquest, and the invasion of England by the Normans "guided by a comet" was a familiar topic for the chroniclers of the time. The abdication of Emperor Charles V was reported to have been influenced by the comet of 1556, but the event had already taken place before the comet made its appearance. Gain Galeazzo, the Visconti Duke of Milan, viewed the comet of 1402 as a celestial sign of his approaching death.

A striking example of the manner in which the comet was regarded is contained in the contemporaneous description by Ambroise Paré, the father of French surgery (1517-1590), in which he speaks of the fear inspired by the comet of 1528. "This comet," said he, "was

so horrible, so frightful, and it produced such great terror in the vulgar, that some died of fear and others fell sick. It appeared to be of excessive length, and was of the color of blood. At the summit of it was seen the figure of a bent arm, holding in its hand a great sword, as if about to strike. At the end of the point there were three stars. On both sides of the rays of this comet were seen a great number of axes, knives, blood-colored swords, among which were a great number of hideous human faces, with beards and bristling hair."

The comet of 1472, apparently, was the first comet to receive scientific study and not to be regarded solely as a cause of superstitious terror. A series of observations were made in Franconia by Johann Müller, of Königsberg, known as Regiomonatanus.

By the time of Tycho Brahe, while comets were not satisfactorily explained, yet they were being considered on a more rational basis, and the correctness of the Aristotelian doctrine was, as in other matters, being questioned. It was belived before this that comets were generated in the higher regions of the atmosphere. But in 1507, on the appearance of a brilliant comet, Tycho, in an elaborate series of observations, satisfied himself that the strange body was at least three times as far off as the Moon and also that it was revolving around the Sun in a circular orbit at a distance greater than that of Venus. Comets subsequently were observed by Tycho and his pupils. His observations in this field led to those ideas of the solar system of his which we have discovered. It was but natural that Kepler, as a follower of Tycho, should have paid especial attention to comets. In 1607 he observed the comet now known as Halley's comet. Kepler believed that comets were celestial bodies which move in straight lines and after having passed the Earth recede indefinitely into space. Assuming that these strangers in the heavens would never reappear, he did not consider that their paths required serious study, for which reason he made no observations to ascertain their movements and test his theory. Before Kepler, Jerome Fracastor (1483-1543) and Peter Apian (1495-1552) had observed that a comet's tail always points away from the Sun, no matter in what direction it may be traveling, and with this observation Kepler agreed, adding as an explanation the supposition that the tail was formed by rays of the Sun penetrating the body of the comet and carrying away with them some portion of its substance. This theory, after due allowance has been made for the change in our conception of the nature of light, is of interest as an anticipation of the modern theory of comets' tails. Kepler found himself compelled in his "Treatise on Comets," 1619, in which the foregoing observations were published, to refer to the meaning of the appearance of a comet and its influence on human affairs. At this time there were striking events enough in the affairs

of Europe to prove any theory of the influence of comets on human life. He realized, however, that comets are very numerous, for he states, "There are as many arguments to prove the motion of the Earth around the Sun as there are comets in the heavens."

The motion of the comets was also studied by Galileo in 1623 as a part of the motion of the Earth in the Copernican theory of the solar system. But the first and most important contribution to the true explanation came from Dörfel of Saxony, who proved from the comet of 1681 that the orbits of comets are either very elongated ovals or parabolas and that the Sun occupied a focus of the curve. Newton, discussing this subject in his Principia, reached independently the same conclusion a few years later and established it as a universal law by incontrovertible mathematical proof.

By the seventeenth century a considerable number of comets had been recorded. John Hevel, of Danzig (1611-1687), published two large books on comets, Prodromus Cometicus (1654) and Cometographia (1668), which contained the first systematic account of all recorded comets.

It was a brilliant thought of Newton's that led him to consider whether gravitation toward the Sun could not explain a comet's motion just as well as that of the planet, and if so, as he took pains to prove in the beginning of the Principia such a body must move either along an ellipse or in one of two other allied curves, the parabola and hyperbola.

Edmund Halley (1656-1742), who had been a friend and active associate of Newton's and had assisted him for several years in the preparation of the Principia, followed Newton's principles in the observation of comets. He computed the paths of the comets of 1680 and 1682, and especially one of 1531 whose appearance was recorded by Appian. His studies contributed much to the material dealing with this subject in the Principia, epecially the later editions. In 1705 he published a Synopsis of Cometary Astronomy, in which he calculated 24 cometary orbits. Discussing in detail a number of these, he was struck with the resemblance between the paths described by the comets of 1531, 1607 and 1682, and the approximate equality in the intervals between their respective appearances and that of a fourth comet observed in 1456. Moreover, there was a historical record of a comet in 1380, as well as in 1305. He at once concluded that all four comets were really different appearances of the same comet, which moved around the Sun in an elongated ellipse in a period of about 75 or 76 years, and he accounted for the small differences in the different intervals between the appearances of the comet by perturbations caused by planets in whose neighborhood the comet passed. He then made the first prediction of the probable reappearance of the comet, assigning the date, 1758, when next it would be seen after a

76-year interval. Halley, no less than modern astronomers, was aware of the disturbance that the presence of the planets might work in a comet and its orbit, and how its time might be altered. He confidently announced the actual appearance of the comet, but left shortly before his death, at the age of 85 years, the following quaintly worded statement in regard to the comet: "Wherefore, if according to what we have already said, it should return again about the year 1758, candid posterity will not refuse to acknowledge that this was first discovered by an Englishman." When the time arrived the comet was looked for by astronomers; the Franch savant, Alexis Claude Clairaut (1713-1765), computed the various perturbations which might have affected its journey. As its path lay through the orbits of Jupiter and Saturn and as it passed close to both of these great planets, his calculations showed that there might be expected a retardation of 100 days on Saturn's account and 518 days for Jupiter. On Christmas Day, 1758, a month and a day before the date assigned by Clairaut, and in the year announced a half century before by Halley, the comet was actually discovered by George Palitzsch (1723-1788), of Saxony, and the great astronomical prophecy was thus fulfilled. A new member was added to the solar system; the wandering and fear-inspiring comet was thus brought into harmony with the other members and made subject to the fundamental calculations of the astronomer. Whatever superstition had attached to these wonderful apparitions had now all but passed, and comets were found to present problems no less interesting than other celestial bodies when their fundamental motions were known.

In 1835 Halley's comet duly reappeared and passed through its perihelion within a few days of the time set for it by astronomers. It was observed, among others, by Sir John Herschel at the Cape of Good Hope. In 1910 this comet returned. It was first discovered by Wolf, of Heidelberg, on September 11, 1909.

In the study of Halley's comet in connection with its appearance, much attention has been devoted by astronomers to its earlier history, particularly that recorded in Chinese and European annals. Messrs. Cowell and Crommelin, at the Greenwich Observatory, have carefully examined the previous work of Hind and have found it in the main correct. Halley's comet unquestionably must be identified with one that occurred in 1066, in the year of the Norman Conquest, a representation of which is now extant in the Bayeux tapestry supposed to have been worked by Queen Matilda and her ladies.

In more modern times comets have been associated with some important development of scientific theory rather than with historical events. The comet of 1811, visible from March 26th of that year until August 17th of the following year, received the attention of Sir Wil-

liam Herschel, who discovered that it shone partly by its own light, which developed as it approached the Sun. This comet had a tail at one time 100 million miles in length and 15 million miles in diameter. Dr. Olbers suggested that electrical repulsion was responsible for the formation of the tail. A comet famous for the fact that it was the first of the family of Jupiter's comets to be discovered was that named for Johann Franz Encke, for many years director of the Berlin Observatory. It was discovered by Pons of Marseilles, November 26, 1818, but in the calculation of its orbit and other elements Encke found that it revolved about the Sun in a period of 3 1/3 years, which is considerably shorter than that of any other known comet. Furthermore, he established its identity with comets seen by Méchain in 1786, by Caroline Herschel in 1795, and by Pons, Huth and Bouvard in 1805. Encke's calculations, after establishing its periodicity, assigned the date of May 24, 1822, for its next return to perihelion, and tho on account of the position of the Earth at that time it was invisible in the northern hemisphere, it was detected at Sir Thomas Brisbane's observatory at Paramátta by Rümker very nearly in the position indicated by Encke. This was only the second instance of the recognized return of a comet, so that Encke's work as an astronomical achievement should be considered with that of Halley.

Biela's comet, discovered by an Austrian officer of that name at Josephstadt, in Bohemia, February 27, 1826, presents as interesting features as that of Encke. It was seen ten days later at Marseilles by the French astronomer Gambert. Both observers announced its discovery and the computation of its orbit in the same issue of the Astronomische Nachrichten. Tho the comet was identified with similar appearance in 1772 and 1805, it was not visible after the latter date with the naked eye. In 1832 Sir John Herschel observed it as a conspicuous nebula without a tail. While the day of active superstition in regard to the appearance of comets had passed with the demonstration of Halley's theory, nevertheless Biela's comet occasioned widespread popular excitement, founded, moreover, on the statements of scientific men that a collision with the Earth might occur. The possibility is one of the remotest of cosmical happenings.

In 1846 Biela's comet reappeared, and when first seen, November 28, presented no unusual appearance. Gradually it became distorted, however, and elongated. Within two months it was divided into two separate bodies, which were visible until April 16th of the following year. This striking phenomenon of a double comet was noted by many astronomers at different observatories, and thus established what Seneca had reproved Ephorus for supposing to have taken place in 373 B.C. and what Kepler had noted in 1618, but without convincing astronomers at large of the correctness of his impression. These two Biela comets contained a small amount of matter and performed their

revolutions around the Sun independently without experiencing any appreciable mutual disturbance, which indicated that at an interval of only 157,250 miles their attractive power was virtually inoperative. Various interesting phenomena showing internal agitation were observed and variations of brilliancy and form were distinctly evident. In 1852 Biela's comet again appeared in its double form, but since that time has not been observed. The disruption occasioned by its proximity to Jupiter in 1841 is believed to have been the beginning of the disintegrating process which resulted in its disappearance.

The greatest comet of the nineteenth century was that of Donati, which was seen by him at Florence, June 2, 1858. By the end of September, when the comet had reached its perihelion, the tail had attained full development, and on October 10 it stretched in a maximum curve over more than a third of the visible hemisphere, representing a length of 54,000,000 miles. For the 112 days during which it was visible to the naked eye the fullest observations were made. The comet stands by itself, as it is not possible to identify it with any other. At aphelion its orbit extended out into space to 5½ times the distance from the Sun to Neptune, and for its circuit, which is effected in a retrograde direction, requires more than 2,000 years, so that its next return should be about the year 4000 A.D. It was computed by M. Faye that the volume of this comet was about 500 times that of the Sun. On the other hand, he calculated that the quantity of matter it contained was only a fraction of the Earth's mass. This shows how almost inconceivably tenuous the material forming the comet must have been—much more rarefied indeed than the most perfect vacuum which can be produced in an air pump. This tenuity is shown by the fact that stars were seen through the tail "as if the tail did not exist." A mist of a few hundred yards in thickness is sufficient to hide the stars from our view, while a thickness of thousands of miles of cometary matter does not suffice even to dim their brilliancy.

Dr. Barnard states that our knowledge of the extremely rapid transformations in the tails of comets dates from the photographs of Swift's comet of 1892, taken at the Lick Observatory, and similar ones taken of the same object by Professor Pickering at Arequipa. While only an insignificant affair visually, and but fairly visible to the naked eye, Swift's comet showed upon the photographic plate the most extraordinary and rapid transformations. One day its tail would be separated into at least a dozen individual streams and the next present only two broad streamers, which a day later had again separated into numerous strands, with a great mass, apparently a secondary comet, appearing some distance back of the head in the main tail, with a system of tails of its own.

The photographs of Brook's comet of 1893 showed such an extraordinary condition of change and distortion in the tail as to suggest some

outside influence, such as the probable collision of the tail with a resisting medium, possibly a stream of meteors. The long series of photographs obtained of this comet showed great masses of cometary matter drifting away into space, probably to become meteor swarms. Had it not been for photography, the comet, instead of proving to be one of the most remarkable on record, would have passed without special notice. Tho these phenomena were so conspicuously shown, scarcely any trace of the disturbance was visible with the telescope. On account of the apparent insignificance of the comet visually, no photographs were made of it elsewhere during its active period. The application of photography to cometary studies has been an important feature of the investigation of later comets, none of which since 1882 have been marked by great brilliancy.

The general nature and appearance of a comet is thus clearly described by the late Professor R. A. Proctor: "When first seen in a telescope, a comet usually presents a small round disk of hazy light, somewhat brighter near the center. As the comet approaches the Sun the disk lengthens, and if the comet is said to be a tailed one, traces begin to be seen of a streakiness in the comet's light. Gradually a tail is formed, which is turned always from the Sun. The tail grows brighter and longer, and the head becomes developed into a coma surrounding a distinctly marked nucleus. Presently the comet is lost to view through its near approach to the Sun. But after a while it is seen again, sometimes wonderfully changed in aspect through the effects of solar heat. Some comets are brighter and more striking after passing their point of nearest approach to the Sun (or perihelion) than before; others are quite shorn of their splendor when they reappear. On the other hand, the comet of 1861 burst upon us in its full splendor after perihelion passage.

"As a comet approaches the Sun a change takes place in the appearance of the coma and nucleus, and in some instances a tail is generated. The process actually observed is generally this: In the forward part of the nucleus a turbulent action is seen to be in progress, leading to the propulsion toward the Sun of jets or streams of misty-looking matter. Sometimes a regular cap or envelope is seen to be projected in this manner toward the Sun, or even a set of envelopes one within the other. The matter thus thrown off is not suffered to pass very far from the nucleus toward the Sun, but is swept away, as fast as formed, in the contrary direction. If the funnel of a steam engine were directed forward, instead of upward, then the appearance presented by the emitted steam as the engine rushed on (against a hurricane, suppose, to make the illustration more perfect) would exemplify the process which seems to be taking place around the front of the nucleus and far behind it as the matter formed is continually swept

away from the Sun. The same Sun which attracts the nucleus seems to repulse the emitted matter with inconceivable energy.

"When we see the tail of a comet occupying a volume thousands of times greater than that of the Sun itself, the question naturally suggests itself: 'How does it happen that so vast a body can sweep through the solar system without deranging the motion of every planet?' Conceding even an extreme tenuity to the substance composing so vast a volume, one would still expect its mass to be tremendous. For instance, if we supposed the whole mass of the tail of the comet of 1843 to consist of hydrogen gas (the lightest substance known to us), yet even then the mass of the tail would have largely exceeded that of the Sun. Every planet would have been dragged from its orbit by so vast a mass passing so near. We know, on the contrary, that no such effects were produced. The length of our year did not change by a single second, showing that our Earth had been neither hastened nor retarded in its steady motion round the Sun. Thus we are forced to admit that the actual substance of the comet was inconceivably rare. A jarful of air would probably have outweighed hundreds of cubic miles of that vast appendage which blazed across our skies to the terror of the ignorant and superstitious.

"The dread of the possible evils which might accrue if the Earth encountered a comet will possibly be diminished by the consideration of the extreme tenuity of these objects. But the feeling may still remain that influences other than those due to mere weight or mass might be exerted upon terrestrial races in the course of such an encounter. On account of their enormous volumes, it is not so utterly improbable that we should encounter them as that we should meet the comparatively minute nuclei. In fact, the Earth actually did pass through the tail of the comet of 1861. At about the hour when it was calculated that the encounter should have taken place a strange auroral glare was seen in the atmosphere, but beyond this no effect was perceptible."

In distinction to the comets moving in regular orbits around the Sun, the possible portions of one much larger cometary body which became dispersed by gravitational action or through violent encounter with the suns surrounding must be mentioned. These comets, which apparently have been seized by the gravitative attraction of the planets, are compelled to revolve in short ellipses around the Sun well within the limits of the solar system. These comets are spoken of as "captures," and while Jupiter, Saturn, Uranus and Neptune each possess families of this kind, it is the first named which are the most important, as they number about 30, and in this family may be included not only the bodies that Jupiter has attracted, but those that have been robbed from other planets. Comet families are not found in the case of the terrestrial planets, because the gravitative power of

the Sun in their vicinity is so much greater than any attractive force which they could manifest. In addition, when a comet enters the inner portion of the solar system, it has such velocity that the gravitational attraction of the planets within these regions is not powerful enough to cause any appreciable deflection. If a captured comet is acted upon by further disturbing causes, its new orbit may be disarranged and it may be again diverted into celestial space.

The facts learned from modern cometary study are summed up by Miss Clerke as follows: "First, comets may be met with pursuing each other, after intervals of many years, in the same, or nearly the same, track; so that identity of orbit can no longer be regarded as a sure test of individual identity. Secondly, at least the outer corona may be traversed by such bodies with perfect apparent immunity. Finally, their chemical constitution is highly complex, and they possess, in some cases at least, a metallic core resembling the meteoric masses which occasionally reach the Earth from planetary space."

The first serious study of the physical nature of comets' tails was undertaken in 1811 by Dr. Heinrich Olbers, the astronomer of Bremen. He assumed that the formation of a tail was due to expelled vapors on which two forces, solar and cometary, acted and balanced each other. In other words, he believed that the tails were emanations, not appendages, and consisted of rapid outflows of highly rarefied matter which, in great part, had become permanently detached from the nucleus.

This theory is especially interesting in the light of modern investigation. It served for many years until that of Bredichin, who in an examination of various comets' tails found that the curvilinear shapes of the outline fall into one or another of three special types as follows: Type 1, or the straightest, is most probably due to the element hydrogen. Type 2 a number of hydrocarbons are present in the body of the comet, while in the third type iron or some element with high atomic weight was assumed. Some comets may have tails of more than one of these forms, as, for example, in the case of Donati's comet, which had a straight as well as a curved tail. Of Type 2, comets with a number of tails have been recorded, such as the one of the year 1744. Bredichin calculated that a repulsive force adequate to produce the straight tail of Type 1 need only be about 19 times as much as the attraction of gravitation, while tails of the second type a repulsive force about equal to 3.2 to 1.5 times that gravitation would suffice, while those of the third type would require a repulsive force about 1.3 to 1 times that of gravitation. These parts are nearly inversely proportional to the atomic weights of hydrogen, hydrocarbon gas and iron vapor, which ratio suggested to Bredichin the composition of the various types of tail. While he was unable to demonstrate that the tails were the result of electrical action, yet he assumed some

hypothetical repulsive force which electrical action seemed to explain better than any other.

Professor E. E. Barnard in 1905 stated that a repellent influence of some sort must come from the Sun, and with it he included an ejecting force proceeding from the comet itself and a resistant force of some kind. The repellent force from the Sun may be found in the pressure of light, which Professor J. Clerk Maxwell assumed must be exerted by light rays according to mathematical reasoning. "Radiation pressure," as it is termed, was not experimentally proven for many years, but in 1900-1901 it was established as a scientific fact by the Russian physicist Lebedev and in America by Nichols and Hull. This principle thus demonstrated, Professor Svante Arrhenius applied cosmically and held responsible for the generation of streams of matter flowing from the comet's head. As the comet approaches the Sun this pressure exceeds the force of gravity and acts upon the cometary substance so as to drive out multitudes of the minute particles in a direction away from the Sun. Such a swarm of particles receiving the light from the Sun would appear as the familiar luminous streamer recognized in the comets' tails.

When examined with the spectroscope, a comet's tail shows a faint continuous spectrum, produced doubtless by the sunlight reflected by the small particles, in addition to spectral bands due to gaseous hydrocarbons and cyanogen. Cyanogen is due to electric discharges, for such discharges are observed in comets whose distance from the Sun is so great that they cannot appear luminous owing to their own high temperatures. In other words, the composition of a comet is not unlike the blue flame of a gas stove, which is a combination of hydrogen and carbon. As the comet dashes toward the Sun and its temperature consequently rises, the spectroscope reveals the presence of iron, magnesium, and other metals in the nucleus. With a closer approach to the Sun the hydrocarbons split up into hydrogen gas and hydrocarbons of a higher boiling-point. Finally, a time comes when these more refractory hydrocarbons in turn decompose into free carbons in the form of soot. Because interstellar space is airless the soot cannot burn, but must accompany the comet in the form of a very fine dust. This dust, propelled away from the Sun by radiation pressure, constitutes the tail of many a comet. Some of the soot particles may be larger than the critical size. They will be jerked forward toward the Sun in advance of the comet to form what is known as the comet's "beard," a rather rare phenomenon.

This phenomenon of the pressure of light is able to explain the fact that the minute particles ejected from the nucleus of a comet can pass over great distances in small intervals of time, which was one of the hardest points to overcome in explaining the rapid change of position of the comet's tail passing around the Sun.

In addition to the light-pressure of the Sun, the electrical energy of the Sun must be called upon to explain the occurrence of tails which are ejected from the nucleus with a force that may be as much as 40 times more powerful than gravitation.

Meteors, often called shooting stars, which in some instances, at least, must be the remains of comets, are small solid bodies which revolve around the Sun, generally in great numbers, following approximately the same orbit, and are encountered by the Earth in its annual revolution. Then they graze the Earth or even fall toward it, but, fortunately for its inhabitants, they seldom reach its solid surface, because they are raised to incandescence and dissipated in vapor by the heat generated by friction in their swift rush through the atmosphere. At certain seasons of the year the Earth traverses comparatively dense swarms of meteors and is subjected to a veritable bombardment. The effect to the eye of these flashing meteors is most striking and brilliant, particularly if the point of the swarm intersected contains a large aggregation of meteors. The apparent radiation of a meteoric shower from a common point or radiant is an effect of perspective, as the meteors of a swarm in reality pursue parallel paths. Three of these meteor swarms are of particular interest, as under certain conditions they give rise to fine displays. These are known as the Bielids, the Leonids, and the Perseids, the first two occurring in November and the last named in August.

The Bielids, deriving their name from the connection of their orbit with that of the comet Biela, are also known as Andromedids on account of their apparent source in the constellation of Andromeda. M. Egenitis, Director of the Observatory at Athens, traced back the Andromedid shower to the times of the Emperor Justinian. Theophanes, the chronicler of that epoch, writing of the famous revolt of Nika in the year 532 A.D., says: "During the same year a great fall of stars came from the evening till the dawn." M. Egenitis notes another early reference to these meteors in 752 A.D., during the reign of the eastern Emperor Constantine Copronymous. Writing of that year, Nicephorus, a Patriarch of Constantinople, states: "All the stars appeared to be detached from the sky and to fall upon the Earth." But it was not until the nineteenth century that Bielids aroused much attention, and then it was in great part due to the fact that apparently the same orbit was occupied by them as by Biela's comet, which we have seen was not observed after its appearance in 1852. The Bielid shower, however, since that time has shown increased activity, which was especially true in the years in which the comet, were it in existence, would have been scheduled to pass near the Earth.

In the case of the Leonids, records of their occurrence go back as far as 902 A.D., which is called "year of stars," because on the night of October 12, while the Moorish Ibrahin Ben Ahmed was dying be-

fore Cosenza in Calabria, "a multitude of falling stars scattered themselves across the sky like rain," and naturally aroused great excitement among those who beheld the phenomenon, which they considered a celestial portent of unusual significance. In 1698 modern history of the Leonids began. A maximum Leonid shower has occurred with considerable regularity at periods of about 33 years from that date. In 1799, on the 11th of November, Humboldt and Bonplandt witnessed a notable display in South America. On November 12, 1833, meteors were said to have fallen as thickly as snowflakes; in seven hours 240,000 were estimated to have appeared. The radiant from which the meteors seemed to come was found to be situated in the head of the constellation of Leo, from which circumstance the name Leonids results. Professor Dennison Olmstead, of Yale University, assigned to this cloud of cosmical particles the path of a narrow ellipse in an orbit around the Sun and intersecting that of the Earth. This marked the beginning of an important department of astronomy. In 1837 Olbers established the periodicity of the maximum shower which indicated a regular distribution of the meteoric supply. In 1866, as conjectured by Olbers, another time of maximum occurrence took place, which seemed to demonstrate that while the Earth cut through the orbit each year about the same date, at the 33-year period the swarm was at a point of maximum density in the orbit. In 1899, however, much disappointment was caused by the failure of the Leonid shower to take place on the scheduled date, a failure which was explained as due to the attraction of one of the larger planets, which had diverted the orbit from its old position so that the Earth failed to pass through the swarm. The cometary connection in the case of the Leonids is shown by the fact that they seem to travel in the orbit of Tempel's comet of 1866.

The Perseids date back to the year 811 A.D., and derive their name from the constellation of Perseus, where their radiant point is situated. They are seen on the 10th of August in continental Europe. As this is the day of Saint Lawrence, they are known as the "tears of Saint Lawrence." But this date is not the only one on which meteors from this swarm are to be observed, for they fall in greater or less numbers from about July 8th to August 22d. They are very rapid in their motion and the trails often persist for a minute or two before they are disseminated. The Perseids have an easterly motion, shifting each night by a small amount. Their orbit cuts the orbit of the Earth almost perpendicularly, and they are supposed to be the débris of an ancient comet which traveled the same path. Various comets, especially that of Tuttle in 1862, seem to have had the same orbit, and the meteors are quite evenly distributed along the path.

There are other swarms of meteors, such the Lyrids, the Orionids, etc., and Mr. W. F. Denning, of England, who has made a specialty

of this field, has accounted for 3,000 other less conspicuous showers. Astronomers have shown that the various meteor swarms and comets move in the same orbits. Accordingly the theory has been proposed that when a comet is captured by a planet the material of the tail is driven off into space and the remaining material, disintegrated by the various forces at work, is distributed along the orbit. Consequently the phenomenon of a meteoric shower occurs when the orbit of a swarm and that of the Earth intersect and when the Earth and meteors arrive at this intersection at the same time. Leverrier showed that the Leonids resulted from the capture of a parent comet in 126 A.D. at the time of a near approach, and that the disintegration, not entirely completed, is already far advanced. He claimed that the Perseids were of much older formation.

Meteors have been observed from the earliest days, but are of such minor importance as compared with comets that they attracted no particular attention. In 1719 Brandes and Benzenberg, at Göttingen, by making simultaneous observations of the beginning and end of the path of a meteor from different stations a few miles apart were able to determine not only its position, but its velocity, and subsequent observations similarly made indicate that meteors appear at altitudes of 60 to 100 miles and that they move over paths of 40 or 50 miles, traveling at a rate of 10 to 40 miles a second.

When a meteor enters the Earth's atmosphere from interplanetary space, the friction of the atmosphere, caused by its high velocity, develops heat and causes it to shed a brilliant light. The temperature of a meteor rises to many thousand degrees Centigrade, and for that reason it is usually consumed before it reaches the Earth's surface. The products of oxidation and disintegration consist simply of dust, which falls on the Earth's surface or is distributed throughout space. In the main, meteors simply contribute dust to the Earth.

The energy of the meteors as well as its mass can readily be ascertained if its distance, the duration of its luminosity, and its brightness are known, for the total amount of light radiated can be calculated on the basis that its entire energy is thus transformed. The mass of a meteor is not particularly large and is usually but a small fraction of an ounce. For the most part it is not larger than a pea or pebble. It is the atmosphere that not only heats these rapidly moving bodies but acts as a protection to the Earth, for if meteors were not thus disintegrated they would fall upon its surface in a constant bombardment. In addition to the meteors seen with the naked eye, estimated by the late Professor Simon Newcomb at not less than 146 billion per annum, there are doubtless ten times as many which pass merely as streaks of light in the field of the observer's telescope.

In addition to the extremely fine dust which settles on the Earth as the result of the disintegration of various celestial bodies, there are

from time to time masses of greater or less size which, rushing into the Earth's atmosphere with a brilliant glow due to the heat generated by friction, fall to the Earth's surface and become more or less embedded. The appearance is most striking, accompanied as it often is by a loud roar like a waterfall and occasionally violent explosions. Thus it is stated that at Cairo, in August, 1029, many stars passed with a great noise and a brilliant light. These bodies, a number of which come to the Earth's surface yearly, are termed meteorites, siderites, uranoliths or aerolites, and apparently are the connecting links between the Earth and outside space. Their nature is none too well known and they present many unsolved problems. It is interesting to know that the great Mexican meteorites at the time of the Spanish invasion were considered holy bodies by the Indians, so that it is inferred that their fall from the heavens was known and was regarded as a supernatural occurrence. In the Greek and Roman records similar attention was paid to the palladium of Troy, to the image of Diana at Ephesus and to the sacred shield of Numa, all of which were said to have fallen from the heavens and were no doubt meteorites.

Meteorites are usually divided into two classes, those composed chiefly of iron and those composed chiefly of stone. Of the 292 actually observed meteoric falls that took place during the last century, only twelve, or about 4 per cent., belonged to the first class, yet in our cabinets the two classes are represented in nearly equal numbers. The explanation of this strange anomaly lies in the fact that unless the fall has been actually witnessed close at hand, very few of the stony meteorites are ever found. Of 328 in the collection of the British Museum, 305, or 93 per cent., were seen to fall. This is partly because these bodies to ordinary inspection appear very like common stones, and therefore are not recognized as meteorites, and partly because owing to their physical and chemical structure they are readily decomposed by the action of the elements.

It is the custom to associate meteorites with falling stars, and to say therefore that they are of cometary origin. This relationship, however, is not as obvious, when we begin to examine into the case, as at first sight appears. A prominent difficulty is that the distribution of the meteorites throughout the year differs very materially from that of the falling stars and fireballs. While these last two are about twice as numerous during the latter half of the year as during the first half, the meteorites are more numerous during the first half of the year. From this we should infer that while perhaps all meteorites are fireballs, only comparatively few fireballs become meteorites. The dividing line between meteorites and falling stars then lies among the fireballs, the swiftly moving ones being allied to the falling stars and the slowly moving ones to the meteorites.

It is now generally accepted that the crystalline and often conglomerate structure of these bodies prove them to be but the fragments of much larger bodies that have in some manner been destroyed or from which they have otherwise become separated. Many believe that the crystalline structure of the iron meteorites indicates a slow cooling, while some say that the structures of the "chondres" of the stony meteorites must certainly have been produced by a very rapid crystallization due to a sudden exposure to a lower temperature.

It was formerly thought by some that these bodies might have been expelled from the Sun. Although it is quite possible that solar explosions in past ages were sufficiently violent to project these bodies with the necessary cometary velocities, yet we cannot believe the Sun to be the direct source of them, since it is improbable that either solid stone or iron should ever have existed upon its surface or within its interior. Nor is it easy to explain how with such an origin the meteorites should have acquired their present orbits.

Some of the earlier cosmogonists referred their origin to the terrestrial or lunar volcanoes. This is manifestly impossible in the case of the Earth, since even prehistoric volcanoes could not have expelled their products with such force that after leaving the confines of our atmosphere they should still retain a velocity of over seven miles per second. Yet this is the speed required to prevent an immediate return to the Earth's surface. Moreover, altho volcanic eruptions in prehistoric times were undoubtedly more frequent and voluminous than at present, it is by no means certain for theoretical reasons that they were then any more violent than they are to-day.

Meteors escaping from lunar volcanoes would not have to encounter a dense atmosphere, and, furthermore, their required parabolic velocity would be appreciably less. But even under the most favorable circumstances, in order to escape both the Moon and Earth a speed of over two miles per second would be required. That attained, they would then be controlled by the Sun and might be picked up at any later time by our planet in its orbit. The objection to this explanation is that no explosive volcanoes have ever been detected upon the Moon, all the craters being of the engulfment type. It is therefore very improbable that such extremely violent explosions could have occurred there.

While, as we have seen, meteorites cannot be the product of terrestrial volcanoes, yet it is suggested by Prof. W. H. Pickering that the stony ones were all of them formed during the great cataclysm that occurred at the time that the Moon separated from the Earth. When the truly enormous pressure on the deep-lying terrestrial strata was suddenly relieved by the departure of the upper layers, which now form our Moon, tremendous explosive energy must have been generated. Considerable portions of our atmosphere must have followed

the larger flying masses, and the atmospheric resistance to the smaller ones, swept along at the same time, would have been much diminished. Altho we can probably never definitely know just what occurred at this time, it is quite possible that considerable quantities of the smaller masses were carried along by the blast of escaping gases and were projected to such distances as to free themselves entirely from the attraction of our planet. This implies a solid crust for the Earth at the date of birth of the Moon, which previous investigations of the place of origin of that body seem to justify.

In support of this view of the terrestrial origin of meteorites we have the fact that twenty-nine terrestrial elements, including helium, have so far been recognized in them, ten of them being non-metallic. No new elements have been found. The six which occur most frequently in the Earth's crust, named in the order of their abundance, are oxygen, silicon, aluminium, iron, calcium and magnesium. The eight most commonly found in the stony meteorites are these six, besides nickel and sulphur.

Nearly all the stony meteorites contain some metallic iron, and some of them contain large quantities of it. But this is also true of some of our basaltic lavas. Indeed, large masses of iron have been found in ledges upon the Greenland coast. Some of this iron contains over 6 per cent. of nickel, but much larger proportions have been discovered in New Zealand, Piedmont and Oregon, where considerable quantities of the nickel iron alloys have been found. According to Farrington, of the twenty-one minerals recognized in meteorites, fourteen have been found in our volcanic products.

It appears to Professor Pickering that the iron and stony meteorites differ from one another in other ways besides their composition. That some of the former are associated with falling stars, and therefore with comets, certainly seems plausible. That the latter are not associated with them seems probable, and if so, whence can they have come if not from our own Earth?

CHAPTER XXI

THE STARS—THE CONSTELLATIONS—METHODS OF NOTING THE STARS

THE ancients assumed that the celestial sphere of the heavens was a reality and even considered it a solid sphere of crystal, on which they observed and marked the positions of the various stars, just as to-day the astronomer assumes for the same purpose an ideal celestial sphere of which the observer is the center and in which declination corresponds with latitude on the Earth and right ascension with longitude. They appreciated that altho the stars moved across the sky and apparently with different rates of motion, yet the distances between any two remained unchanged. For this reason they imagined that the stars were fixed on the celestial sphere. The motion of some of the stars about a center or pole which coincided with the Pole Star was observed, and the two poles in the heavens were early assumed. But the most important observation of the ancients was the relative position of the Sun and the stars. A succession of such observations early showed that the stars were gradually changing their position with respect to the Sun or that the Sun was changing its position with respect to the stars.

Thus the stars obviously vary in position and magnitude, yet in ancient times little was conceived as to their nature or possible origin. There was, of course, the fundamental distinction between the planets or moving bodies and the idea of the fixity of the stars, which was early established and persisted for many centuries, even tho Giordano Bruno (d. 1600) vaguely suggested that the suns of space move. In 1718 Halley had announced a shifting in the sky of Sirius, Aldebaran, Betelgeux and Arcturus since the time of Ptolemy's catalogue, and similar conclusions were reached by various other astronomers. But it was only in 1838 when Bessel with the heliometer was able to detect a motion of the star 61 Cygni that it was clearly and conclusively demonstrated that the stars move through space as well as other bodies in the universe.

The stars were supposed by the ancients to be situated on the celestial sphere at a distance greater, it is true, than the planets; yet as they were observed year after year in essentially the same positions they were held as fixed and immovable and a bodily rotation of the celestial sphere itself was assumed. Just as the ancient

mind had given to the planets the names of gods and goddesses, so the wise men of antiquity assigned to the stars similar names or those of animals, the natural result of their vivid imagination. This they did also with groups of stars with even greater play of the inagination.

The idea of grouping the stars into constellations dates from the earliest times. In fact the names long ago given to many have persisted until to-day, tho it must be confessed that they have often proved a cause of embarrassment to the student of astronomy. The modern mind finds it difficult to group in imagination a series of bright points of light in the shape of some mythological hero, bear, dog, serpent or other animal. In most cases the choice had been made in a most arbitrary manner, and Sir John Herschel has truly remarked: "The constellations seem to have been purposely named and delineated to cause as much confusion and inconvenience as possible. Innummerable snakes twine through long and contorted areas of the heavens where no memory can follow them; bears, lions and fishes, large and small, confuse all nomenclature."

The names of the constellations as we know them are doubtless of Greek origin, borrowed from Chaldean and Egyptian astronomy. For the most part the names are Greek. The most important are those through which the ancients believed that the Sun passed in its annual circuit of the celestial sphere, or, in other words, those through which the ecliptic passes. For thousands of years these constellations have been used to identify the position of the Sun, especially as the Sun, Moon and five planets were always to be found within a region of the sky extending about 8 degrees on each side of the ecliptic. To this strip of the celestial sphere the term "zodiac" was given, for with one exception all of the constellations it contained were named after living things. It was divided into twelve equal parts, forming the familiar signs of the zodiac, through one of which the Sun passes every month. These signs were made up of a number of stars grouped into constellations. Their names may still be seen, with but unimportant changes, in a modern almanac just as they figured in early Greek days. The names as given in Latin are Aries, Taurus, Gemini, Cancer, Leo Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius and Pisces.

Just how the stars were originally grouped to form the constellations by the ancients history does not record. In an article in the Scientific American it is stated that "the first reliable information regarding the Greek sky is obtained from Eudoxus of Cnidus, an astronomer who lived about 370 B.C. His work furnished Aratus, who lived a hundred years later, with material for his great astronomical poem.

"'In great numbers,' says Aratus, 'and in various courses the stars

incessantly move around the motionless skies. The axle stands immovable. In the midst the Earth is suspended in equilibrium, while the heavens swing around it. The poles bound the axle on both sides. These are encircled by the Bears, that revolve around back to back separated by the Dragon's manifold coils.'"

Eratosthenes (about 170 B.C.) enumerates these constellations, and not only tells the mythological stories but indicates the positions and numbers of stars in every figure, differing from Aratus only in a few particulars.

"Ptolemy gave forty-eight constellations. The figures were the same as the old constellations of Aratus with a few additions. The stars, however, were marked in their proper places and defined as to latitude, longitude and magnitude.

"After Ptolemy a long period ensued during which the astronomical charts were unchanged. It is to the Arabs in the eighth century that the next advance is due. The Caliphs of this period, among whom was Haroun al Raschid of 'Arabian Nights' fame, were friends to science and gathered around them men of learning, such as the famous astronomers Ulug Bekh, Fergani, El-Batan and Abdelrahman Sufi. To a great extent they were satisfied with Ptolemy's work, and altho they retained a great many of the Greek star names, they added a number derived by tradition from the ancient Arab names. Abdelrahman Sufi wrote a detailed and exhaustive account of the Greek constellations, carefully following Ptolemy, and at the same time he treated of the ancient Arabian heavens.

"So strong was their objection to the personal element that when the Greek Zodiac was incorporated by the Arabian astronomers they indicated the names of the objects carried by the characters instead of the characters themselves. Thus Virgo was called the Ears, on account of the wheat she held in her hand; Sagittarius was not the Archer but the Bow, and Aquarius not the Water-bearer but the Well Bucket.

"When the great mixture of Arabian folk-lore was combined with the Greek sky many of the star names were retained, but occasionally the Greek names were changed; for instance, the beautiful red Antares in Scorpio was appropriately called the Scorpion's Heart.

"In 1433 Ulug Bekh made at his observatory in Samarkand the most correct catalogue of stars up to that period. The famous astronomical tables compiled under Alphonso X. of Castile date from 1252, and next in importance was the great catalogue of Tycho Brahée (1546-1601).

The designation of individual stars probably antedated the idea of constellations; this we may infer from the allusions to the star Arcturus in Job (ix, 9). The two stars Castor and Pollux date from classical antiquity. The names of most individual stars now used are

of Arabic origin, which fact accounts for the number of names not Greek or Latin. Thus Aldebaran is a corruption of Al Dabaran, the follower. The modern system of naming stars, however, consists in identifying them with the constellation and then in giving them a separate designation by adding a letter of the Greek alphabet. Thus the brightest star of a constellation is called Alpha, the next Beta, etc. This rule, which was devised by Beyer for his Uranometria, or star catalogue, published in 1601, has not been followed in all cases. When the number of stars was such as to exhaust the Greek alphabet the Roman was employed and in same cases italics. Flamsteed, the first Astronomer Royal of England, in his catalogue of stars made from observations at Greenwich (1666-1715), introduced a system of numbering the stars. In modern star catalogues both the Beyer letter and the Flamsteed number are often found.

Of the individual stars, tho not the brightest, perhaps the most important to us is Polaris, the "North Star" or "Pole Star," which is in a straight line with the two stars marking the bottom of the Dipper, which are termed "the pointers." It is five times as far away as the interval between the pointers and very nearly occupies that point of the heavens toward which the north pole of the Earth's axis is directed. To the observer on the Earth it appears to mark the north. Its position, however, varies with its latitude. It has a certain circular motion, due to the slow shifting of the direction of the Earth's axis, known as precession, so that in the course of some twelve thousand years it will be displaced from its position as pole star, and Vega, a pale blue star of the first magnitude in the constellation Lyra, will assume its place.

It was not until the time of Sir William Herschel that a successful attempt was made to determine the parallax of a star and to ascertain the distribution of stars in the heavens. Herschel assumed that the distances of the stars depended upon their brightness.

It was by Bessel's memorable observations that the angular motion of the star "61 Cygni" was determined in 1838. His calculations showed that the distance of this star was about 400,000 times the distance of the Sun, or $400{,}000 \times 93{,}000{,}000 = 37{,}200{,}000{,}000{,}000$ miles. This was the first direct solution of a problem which long before the day of Aristotle had puzzled astronomers.

If it is difficult to realize the distance of the planets from the Earth and the Sun in the solar system and the extent of their orbits, what must be said as to the distance of Earth or Sun from the stars? A new unit of length was made. A luminous body emits waves which are propagated through the ether at the rate of 186,300 miles a second, or, in round numbers, six billion miles a year. Accordingly the "light-year" was taken as our unit in discussing the distance of the stars. Thus the light from Bessel's star, 61 Cygni,

would take more than six years to reach the Earth. But 61 Cygni is not our nearest star. Subsequently investigation showed that this place belonged to Alpha Centauri, which is four and a third light-years from the Earth and probably ten billions of miles nearer to us than any other member of the sidereal system. Sirius is twice this distance, or eight and a half light-years; Vega is about 30 years, Capella about 32 and Arcturus about 100.

If the parallax and distance of a star are determined, it is possible to make some approximation of its mass in the case of binary stars revolving in known orbits. The components of the double star Alpha Centauri, to which we have referred, revolve around their common center of gravity at a mean distance of nearly twenty-five times the radius of the Earth's orbit. As they require 8 years for a period of revolutions, the attractive force of the two together must be twice that of the Sun. With single stars such a computation cannot be made. Knowing their parallax, however, it is possible to estimate from their size and brilliancy some of the splendid stars in the heavens, such as Canopus, Betelgeuze and Rigel, and to realize that they are thousands of times greater than the Sun and suffer in comparison by their infinite distances. For it must always be remembered that the brilliancy of a star depends not only upon its intrinsic brightness but also upon its distance from the Earth.

For a few other of the visual binary stars data are available for computing their masses. Thus Sirius, which radiates 32 times as much light as the Sun, is supposed to have a combined mass for its two constituent stars of 3.7 that of the Sun; Procyon, 0.6 that of the Sun; Cassiopeia, 1.8; 70 Ophiuchi, 1.8, and 85 Pegasi, 11.3. The average distance of the stars of a pair of those in the above list from each other is 23 times the distance of the Earth from the Sun, or a little greater than the mean distance of Uranus from the Sun.

CHAPTER XXII

HOW TO KNOW THE STARS

In a valuable and accurate work by Kelvin McKready, called "A Beginner's Star-Book," the author says: "Just as there may be a pleasurable familiarity with the flowers without any great knowledge of botany, so there may be a pleasurable knowledge of the stars without any very large acquaintance with the technicalities of astronomy. Indeed, the pleasure of the stars may be the pathway to their science, just as a homely, familiar knowledge of the flowers will lead to an understanding of their botany.

"After all, astronomy is not the most important thing, by any means, that the stars have to teach us. To know them is to know a world that is intrinsically beautiful."

In order to know the constellations there must be a beginning and this beginning is at the Pole Star, the star to which the two stars that form the side of the Dipper (or Great Bear or Plough) furthest from the handle, point. Night and day the Dipper is in the sky, pointing to the Pole, revolving round it (as do all the stars) in just four minutes short of one full day of twenty-four hours.

Consider the Pole Star as the hub of a wheel and the two pointers of the Dipper as one of the spokes. What is the spoke most nearly opposite? If a line be drawn from the star nearest the bowl in the handle of the Dipper through the Pole Star it will strike the flashing W or M shaped constellation of Cassiopeia's Chair at about the same distance from the Pole Star.

Once more using the Dipper as a key-group, draw a line from the end of the handle to the Pole Star, but not beyond it, the line will pass almost through the second largest star of the Little Dipper of which the Pole Star is the end of the handle, which curves up instead of down as in the Great Dipper.

Take now the Little Dipper. A line drawn through the handle will point to the constellation of Auriga, the charioteer, in which lies the brilliant yellow star Capella (the She-Goat) attended by the "three kids," which form an acute triangle near the brilliant star. This constellation, once recognized, is always easy to rediscover, and since it makes almost a right angle to the Pole Star with the Dipper, it gives a further key to the stars that never pass below the horizon in the northern sky.

Between the Pole Star and the beginning of the M or the end of W (according to its position) of Cassiopeia's Chair is the apex of the wedge-shaped constellation Cepheus. If a line be drawn from "the kids" of Auriga, through this apex of Cepheus, it will almost touch (equidistant from the Pole Star as Capella) the brilliant blue star Vega of the constellation Lyra, accompanied by a small double star. The group is like a diamond-shaped train, trailing behind Vega and its companion. Almost opposite Capella, these two stars brightly mark the northern sky. Vega may be checked by using the inner side of the bowl of the Dipper as pointers.

To recapitulate. There is the Pole Star and around this (in the latitudes of the United States), circle a number of stars that never sink below the horizon. They occupy a permanent station in our sky. It is as though a ring were drawn with the pole star as centre and the horizon as radius. In Vermont the Pole Star is high and the circle large; in Florida, the Pole Star is low and the circle smaller. But the Dippers, Capella with the kids, Cassiopeia, and Vega with the diamond-shaped train will always be present to point the rest of the constellations, which may be considered as outer rims of that great wheel of which the Pole Star is the Hub. These four groups learned, the rest is easy.

Let us see, now, how these few key-groups in the northern sky give the clues to the rest of the starry heavens. A line drawn from the Pole Star through Vega will show the splendid constellation of Orion, whose studded belt is the most characteristic feature of all our winter skies, although, so far from the Pole Star is its place in the glittering procession that it appears above the horizon for only 10 hours out of the 24. At 8 p. m. on November 20th the stars of the constellation Orion will be rising and in the sky all night, at 8 p. m. on February 20th they will be at their height and will be visible half the night, at 8 p. m. on April 20th they will be visible though setting. The three bright stars close together and in a line from the belt, and the two stars of the first magnitude at right angles to them are named Rigel and Betelgeuze.

The three stars of Orion's belt point to the Pleiades, most famous of all star clusters in the heavens, distant about one and a half times the apparent span between Rigel and Betelgeuze. Of these the naked eye sees six or seven stars in the cluster, but telescopic photography reveals over 2,500.

Midway between Orion and the Pleiades, lies the great red star Aldebaran, chief of the constellation of Taurus, surrounded by a second star cluster, the Hyades. The three stars in this belt in the other direction point to Sirius, in the constellation Canis Major, the brightest of all objects in the sky.

Take next another of our northern sky key groups. A line drawn

from Cassiopeia's Chair through the Pole Star will lead to the constellation of Corvus (the Crow) four stars arranged in an irregular oblong, with a fifth star off one corner on a line with the apparent top, thus making a pointer of three stars to a first magnitude star, Spica, in the constellation of Virgo.

Next in brightness and importance may be held the fan-shaped constellation Scorpius (the Scorpion). The red-hued first magnitude star, Antares, is in the handle of the fan. It may be found very easily from the constellations already known, for a line from Aldebaran, in Taurus, through the Pole Star, leads direct to Antares.

Its double set of three will always enable it to be closely marked and it dominates the midsummer sky as Orion does that of midwinter.

Note again the bright star Vega in the constellation Lyra, which will be remembered by its diamond-shaped train. In the early autumn sky will appear a group of three stars in Aquila, one, Altair, of the first magnitude. These resemble the handle of the fan in Scorpio, and these three point directly to Vega. This forms a double check, assuring the observer of the correctness of his placement of Vega and preventing him from mistaking Scorpio and Aquila. To make still more sure he will find that the three stars of Aquila point (in the opposite direction from Vega) to a tiny group of three faint stars, all in a line and forming the guiding points of the constellation Capricornus.

Returning again to the Dipper, it will be found that the line to the Pole Star, if carried onward, in the autumn and early winter evenings, will point directly to one of the four large stars that form the Great Square of Pegasus. This Square may be looked on as a Super-Dipper, with the mouth narrowing at the top and the handle arranged like the Great Dipper. The outermost star of the handle, however, does not belong to this constellation, but is Algol, a famous variable star in the constellation of Perseus.

Let Algol, now, be taken as a guide point. It will be found that a line drawn from Algol right between the two bright stars in Cassiopeia's Chair will point to Deneb, one of the greatest stars of all the sky, at least a thousand times brighter than our sun, though inconceivably far away. It follows Vega in the silent circling march through the sky at a distance a little less than the distance between the nearest pointer and the Pole Star. From Deneb a line drawn through the outermost pointer of the Great Dipper will lead to Regulus, a first magnitude star in the constellation of Leo, appearing like a sickle with Regulus as the handle.

Two other great pairs remain, of which Gemini the Twins, are the most familiar. These may be found by a line drawn from the outer-

most star of the handle of the Great Dipper through the outermost of the Pole Star pointers, which line leads directly to Pollux, apparently the largest, though it is a multiple star of six stars. The twin star, Castor, is very near to it, as near as the two bright stars in Cassiopeia's Chair.

Now, if a line be drawn from the Pole Star through Castor it will fall directly upon Procyon in the constellation of Canis Minor, the Little Dog. It is a white star of the first magnitude. It heralds the march of the sky's greatest luminary—Sirius, the Dog Star, in the constellation of Canis Major, the Great Dog. If those marvellous markers of the southern sky—the belt of Orion—be taken as a centre, then spreading over 45 degrees of the heaven is a diamond-shaped figure with the belt of Orion forming the shorter diameter of the diamond, and the longer diameter being formed by Sirius and Aldebaran.

Here, then, is a key to the sky in three great groups: (1) to the north the circumpolar stars with the Dipper and W-shaped Cassiopeia opposite each other, and with Vega of the diamond train and Capella with the little triangle of the "Kids" opposite each other; (2) to the south in winter evenings, Orion and the vast diamond formed with Sirius and Aldebaran pointing to the Pleiades; (3) to the south in summer evenings the two similar groups of three, the fan-shaped Scorpion and the Eagle pointing to the diamond-shaped train of Vega. Turn to the north on any evening of the year and you will see this key group of the Pole Star hub and its spokes. Also to the north in midwinter (at 9 p. m.) Castor and Pollux will show high up to the right; in spring they will be almost over head; in summer they will be far to the left; in autumn to the right the Pleiades appear, heralding Orion's approach.

Turn to the south on a midwinter evening (9 p. m.), the whole great diamond with Orion as its centre glitters to the left and the Great Square of Pegasus like a still Greater Dipper near the zenith to the right; on a spring evening Orion will be slightly to the right, with Sirius glittering full before you; while Corvus points to Spica on the right; on a midsummer evening Corvus points to Spica on the left, while diagonally the square of Corvus points upward to Arcturus, the first magnitude star of the constellation Bootes the Hunter immediately in front and high, the fan-shape of Scorpio low and the three stars of Aquila pointing to the diamond train of Vega far over to the left; on an autumn evening, Scorpio will be far over to the right with Aquila in front pointing to Vega directly overhead, to the left the Great Square of Pegasus, and if the night be clear and the horizon unobstructed, the first magnitude star Fomalhaut may be seen, pointed by the outer end of the Square of Pegasus.

In this very brief outline, the places of every first magnitude star

visible in the United States have been noted, with many lesser stars, and the constellation of which they are a part.

The planets follow a general track, or path, and all follow approximately the same apparent path through the stars. No one ever saw (or could see) a planet near the Great Dipper or Orion. Their path is like the "lane" of a steamship line on the apparently trackless ocean, save that the planets are unswervingly true to their course. In the foregoing "pointers" to the stars, some of the constellations mentioned lie on this path, these are in italics. The path runs through the following constellations in order: Aries, the Ram; *Taurus, the Bull; Gemini, the Twins;* Cancer, the Crab; *Leo, the Lion;* Virgo, the Virgin; Libra, the Scales; *Scorpio, the Scorpion;* Sagittarius, the Archer; *Capricornus, the Goat;* Aquarius, the Water-Bearer; Pisces, the Fishes. Remembering that the stars appear to rise in the east and set in the west, like the Sun, it will be easy to fill in the zodiacal constellations not heretofore mentioned, by plotting the circle of the planets' path, known as the ecliptic, and inserting the constellations lacking, in the proper places on the circumference. On this path the planets may be found, and any apparent first magnitude star which fails to fit into the foregoing schematic arrangement and is on the plane of the ecliptic is probably a planet. For example—Saturn is in Taurus the first half of 1916, and therefore passes inside Aldebaran; from then until July, 1918, he will be in Gemini (near Castor and Pollux), passing next year into Cancer, then into Leo, not reaching Virgo until October, 1922, and passing into Scorpio in November, 1925. In the case of Mars (using very rough terms), since the Mars year is 686 days, the circle of the ecliptic is made by this planet in a little less than two years, or an *average* stay of two months in each constellation (the constellations vary in size). Saturn's year is 29.46 Earth years and Jupiter's year is 11.86 Earth years.

One word more may be added concerning the finding of the stars, and that is the remembrance of their colors. In the glorious blaze of Sirius shines a delicate shade of green. Rigel is distinctly blue-white and there is a pearly luster about Capella that belongs to no other star. Aldebaran, Betelgeuze and Antares are all red stars, but in hue there is a decided variance. Aldebaran has the shade of a rich rose, Betelgeuze is orange and Antares may be described as fire-red. Each of these may easily be discriminated by the naked eye. A good method is to look alternately at Aldebaran and Rigel (in Orion), then at Betelgeuze and Rigel and back to Aldebaran. The color differentiation is likely to strike you suddenly and it is one not easily forgotten. If the observer possesses a good opera-glass or a field-glass, the difference that appears when the stars are viewed on a clear, frosty night is amazing. A good opera-glass, which need not be expensive, but which ought to fit the eyes (in breadth), and which mag-

nifies three times, is, in many respects, an instrument that affords more interest to the amateur than a small telescope. Even if an observer owns a telescope, he will still find value and pleasure in the larger field of an opera-glass despite its low magnifying power. Galileo created modern astronomy with an instrument of less value than a modern opera-glass. And what is perhaps its chiefest good, is that one cannot help but see with the naked eye what one has learned to know through a glass. It is the gateway to a world of wonder and beauty that opens every night when the glare of day has gone.

CHAPTER XXIII

THE MOTIONS AND BRIGHTNESS OF THE STARS

THE term "fixed star," which has survived from ancient times, we have already found is but relative and that all stars have some motion. If the position of one of these so-called fixed stars is noted by observing the time and the height at which it crosses the south point in the sky, and this observation is compared with accurate records which we have, going back nearly 200 years, it will be found that quite a number of the stars are moving slowly across the sky. This movement is termed *proper motion,* which, as seen from the Earth, is at the best an exceedingly minute quantity. Thus one star, and that the most rapid, has moved about the diameter of the Moon in the last 300 years, or an amount which the telescope is quite incapable of detecting. It may be said in passing, however, that the actual observation of fixed stars from the Earth after an interval of, let us say, 100 years, would show more difference. Yet this is due, not to motions of the stars, but to alterations in the direction of the Earth's axis and other causes which give apparent and common motions.

The maximum proper motion is that of the eighth-magnitude star No. 243 of the fifth hour in the Cordova zone catalogue. The star has an apparent drift of 8″.7 annually, which would carry it round a circle of 360° in 149,000 years if it moved uniformly at its present rate. This amount can be appreciated when it is stated that two centuries would be required for a change in position equal to the diameter of the Moon. Arcturus, since the time of Ptolemy, has moved more than a degree and Sirius about half as much, the motions of these two stars having been detected first by Halley in 1718. In fact, the late Professor Newcomb said that if Hipparchus or Ptolemy had made exact determinations of the positions of the stars and to-day should arise from a long sleep, Arcturus would be the only star in which they, or the priests of Babylon for that matter, could detect any change in position relatively to the other stars of the heavens. There is no case in which this quantity is as large as a foot-rule seen at a distance of 50 miles, and for comparatively few miles is this motion certainly appreciable.

The study of the proper motion of stars indicates that, on the whole, the stars are opening out from a point near Vega and closing in to

the opposite point. Professor Kapteyn finds that the stars may be divided into two great classes having on the average proper motions quite different in direction and magnitude, and that these two systems are moving through each other, one from a point in the south of Hercules and the other from a point in the Lynx. In the latter class the solar system doubtless belongs, for it seems to be traveling toward that portion of the heavens occupied by Lyra.

How is it known that stars are moving in the line of sight? Millions and millions of miles away a star may be approaching the Earth, and yet through the telescope there is no change of position and no appreciable change in magnitude. But here use is made of an ingenious principle, which takes its name from its discoverer, Christian Doppler (1803-1853), a physicist of Prague, who made an experiment with quite another object in view. Placing some musicians on a railway car and taking his stand on the platform, he noticed that the pitch of the sound was raised as the moving train approached him and was lowered after it had passed and was receding. If this could happen in sound, why not in light, altho the vibrations occur infinitely faster, so that the color of a luminous body (equivalent to pitch in sound), would be affected by its motion? In 1868 Sir William Huggins successfully applied Doppler's principle. If a star is coming toward us or receding there occurs a displacement in the spectra of the manifold light waves varying from the fundamental value of the velocity of light, 186,000 miles a second. When a star approaches, the light wanes are crowded together; when it recedes they are drawn apart. Now as the number of the vibrations of the light waves and their length determine the color of light or the position of waves in the spectrum, by microscopically comparing spectrum photographs of the same star and noting the displacement of the Frauenhofer lines it can be determined whether that star is approaching or receding.

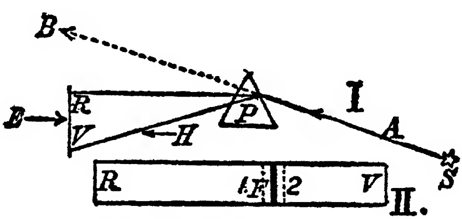


Fig 41—Doppler's Principle.

The pencil of light, A., coming from the star, S., would pass B. if the prism, P., were removed. The glass separates the stellar light into all the colors it may contain. The red rays are bent to R. and the violet rays to V., forming with the colors between, the spectrum of the star.

Doppler's law has been explained very simply by Prof. Edgar Larkin as follows: "In the diagram (Fig. 41) A is a ray of light from the star S, falling on the side of the prism P, which has the property of separating any mixture of light into separate waves. Light from the Sun or stars is made up of a vast number of colors, all appearing between the limits red and violet. Had the pencil A not encountered the glass, it would have passed to B. But the prism separates the white light into colors which can be projected on any white surface. The red is invariably bent out of its original direction the least, the violet most, and will respectively pass to R and V, with every other color between. The shorter the waves the greater their deflection from a straight course. Red waves run 33,000 to an inch and violet 64,000. An eye at E would see all the colors between R and V direct and at H by deflection, if a screen is allowed to receive the light from R to V. Solar and stellar spectra are crossed at right angles by black Frauenhofer lines. Take any one, say F, anywhere in the spectrum and measure its position with micrometer. Then the eye, either at E or H, would see a spectrum as outlined in the lower diagram of Fig. 41, extending like R, 1, F, 2 ,V. Let the prism move at great speed, such as that due to the velocity of the Earth, toward the star, or let the star move toward the Earth. Then the line F will move to 2, or toward the violet end. But if the Earth and stars move in opposite directions, the line F will move to 1, or toward the red."

After the more brilliant stars of the heavens had been identified and their positions determined with as much accuracy as possible with the methods of observation and instruments available to the ancient astronomer, the next development was to compare their relative brightness. In 134 B.C., at the time of Hipparchus, a catalogue of stars was prepared which was said to have been suggested by the sudden appearance of a new star in the constellation of the Scorpion. The stars were divided into six magnitudes, according to their brightness. The catalogue of Hipparchus, containing as it did 1,080 stars, has since proved most valuable to astronomers. Next came Ptolemy's great "Almagest," published in 138 A.D., which contained a catalogue of 1,028 stars, doubtless based on that of Hipparchus. Ptolemy used a scale of stellar magnitudes, which has continued in use to the present time. The brightest stars of the sky, such as Sirius and Arcturus, were regarded as of the first magnitude, and the faintest stars visible to the naked eye as the sixth. Ulugh Begh, about 1450, also published a star catalogue based on Ptolemy, but with careful measures. In 1580 Tycho Brahe published a star catalogue containing the records for 1,005 stars. A supplement carrying this to the South Pole was added by Halley, who went to St. Helena in 1677 for the purpose of making observations of the southern heavens.

No important additions to the knowledge of the brightness of the

stars were made until Sir William Herschel, the greatest of modern astronomers, brought his powerful telescopes to bear on the heavens. He found that when two stars were nearly equal, their difference could be estimated very accurately. Herschel's magnitudes for 2,785 stars observed over a century ago, have an accuracy nearly comparable with the best work of to-day.

In 1844 Argelander proposed to modify Herschel's method of using numbers instead of points of punctuation to denote the intermediate brightness between the various magnitudes, a method known by his name. His catalogue, the great Bonn Durchmusterung (1799-1875), contains as many as 324,198 stars visible in the northern hemisphere. After mere judgment with the eye, it was but natural that some more accurate means should be employed, and various photometers, to which we have referred elsewhere, were eventually adopted for the purpose of gaging stellar brightness.

As a result of modern methods of classification, the number of stars of the first six magnitudes visible to the naked eye is about 5,000. These are grouped in the following order: First magnitude, 20; second magnitude, 65; third magnitude, 190; fourth magnitude, 425; fifth magnitude, 1,100; sixth magnitude, 3,200. It has been estimated that over 100,000,000 stars are visible within the range of present visual and photographic instruments.

The first-magnitude stars number only about 20 and on account of their conspicuous brightness serve as landmarks in the study of the heavens. Their names, constellation, magnitude and color are given in the following table.

Star	Constellation	Magnitude	Color
Sirius	α Canis Majoris	*—1.4	Bluish white
Arcturus	α Bootis	0.0	Orange
Vega	α Lyræ	0.2	Pale blue
Capella	α Aurigæ	0.2	Yellowish
Rigel	α Orionis	0.3	White
Canopus	α Argus	0.4	Bluish
Procyon	α Canis Minoris	0.5	White
Betelgeux	β Orionis	0.9	Ruddy
	α Centauri	1.0	White
Achernar	α Eridani	1.0	White
Altair	α Aquilæ	1.0	Yellowish
Aldebaran	α Tauri	1.0	Red
Antares	α Scorpionis	1.1	Deep red

* When a star outshines a star of the first magnitude it is no longer possible to designate its brightness by 1. Hence the numerical expressions 0.2, 0.3 and —1.4 in the foregoing table.

Star	Constellation	Magnitude	Color
Pollux	β Geminorum	1.1	Orange
Spicca	α Virginis	1.2	White
	β Centauri	1.2	White
	α Crucis	1.3	Bluish white
Fomalhaut	α Piscis Australis	1.3	Ruddy
Regulus	α Leonis	1.4	White
Deneb	α Cygni	1.4	White

In connection with stellar photometry, it has probably occurred to the reader that photographic charts would prove very serviceable, as the brightness of the photographed image could be used. Such indeed is the case. Astronomers interested in stellar photometry have devoted no little attention to the study of these charts and plates.

CHAPTER XXIV

VARIABLE AND TWIN STARS

After the various stars in the heavens were classified according to their brightness or magnitude it became apparent that there were striking and important variations in their brilliancy. When Hipparchus compared his lists and catalogues of the brightest stars in the sky with those of earlier observers, he was duly convinced of the occurrence of changes in their position and brightness. This was strikingly emphasized during his own lifetime, when, as we have seen, a bright star flashed up in the constellation of the Scorpion and then slowly faded away. Such changes as this in part induced Hipparchus and other ancient astronomers to make their star catalogues, for it was realized by them that there were from time to time new stars and a large number of variable stars which, while but a small part of the host of stellar bodies, nevertheless existed in considerable number. Unlike other astronomical phenomena, these variations in stars cannot always be predicted. In many instances they obey no rules, and especially in the case of new stars, or "novæ," they blaze up in sudden glory, remaining bright and then perchance fading swiftly away in darkness. For convenience these variable stars have been classified into groups, all containing prominent examples and differing considerably from one another. These classes may be summarized as follows: (1) New stars, or "novæ," consisting of a few stars that appear suddenly like the star in the constellation Scorpion discovered by Hipparchus; (2) variable stars of long period, fluctuating in light by large amounts during periods of several months; (3) stars whose variations are small and irregular; (4) variable stars of short period; and (5) the so-called Algol variables, which are usually of full brightness and at regular intervals grow faint owing to the interposition of a dark companion between the star and the Earth.

Variable stars have long been known, but only about 250 were recognized by astronomers until photography and spectroscopy were applied to their discovery. Three remarkable discoveries, Prof. W. H. Pickering, of Harvard College Observatory, states, are responsible for greatly increasing the number. "The first was by Mrs. Fleming at Harvard College Observatory, who, in studying the photographs of the Henry Draper memorial, found that the stars of the third type,

in which the hydrogen lines are bright, are variables of long period. From this property she has discovered 128 new variables and has also shown how they may be classified from their spectra. The differences between the first, second and third types of spectra are not so great as those between the spectra of different variables of long period. The second discovery is that of Professor Bailey, who found that certain globular clusters contain large numbers of variable stars of short period. He has discovered 509 new variables, 396 of them in four clusters. The third discovery, made by Professor Wolf, of Heidelberg, that variables occur in large nebulæ, has led to his disclosure of 65 variables. By similar work Miss Leavitt, of Harvard, has found 295 new variables. The total number of variable stars discovered by photography during the last fifteen years is probably five times the entire number found visually up to the present time. Hundreds of thousands of photometric measures will be required to determine the light-curves, periods and laws regulating the changes these objects undergo."

The discovery of novæ, or new, temporary stars (the first class mentioned), continued from the time of Hipparchus to the invention of the telescope. The Star of Bethlehem may have been of this character. In November, 1572, a brilliant new star appeared suddenly in the constellation of Cassiopeia, which was observed by Tycho Brahe during the sixteen months of its life. During this time it rivaled Venus at its brightest and revived Tycho's interest in astronomy, which at the time was beginning to wane. He wrote at considerable length a description of the star, published in 1573, and Kepler subsequently remarked that "if that star did nothing else at least it announced and produced a great astronomer." In modern times the most striking nova was a star which was discovered in Perseus in 1901, by the Rev. Dr. Anderson, of Edinburgh, an amateur, who in 1892 had discovered a nova in the constellation Auriga. In the sudden appearance of Nova Persei, suggests Arrhenius, we evidently witnessed the magnificent termination by collision of the independent existence of two heavenly bodies. Since that time four important novæ have appeared: Nova Geminorum, 1903; Nova Aquilae, 1905; Nova Lacertae, 1910, and Nova Geminorum No. 2, 1912.

Typical of the second class of variable stars which exhibit marked irregularities in period and in brightness similar to those of the new stars is Eta in Argus, which in 1677 was classed as a star of the fourth magnitude and in 1687 and 1751 of the second and in 1827 of the first magnitude. Then Herschel found that it fluctuated between the first and second magnitudes. In 1837 it increased rapidly in brilliancy and in 1838 so far outshone the typical first-magnitude stars that its magnitude was denoted by 0.2. But in the following year it declined to the first magnitude and there remained until 1843, when it

rapidly brightened until it outshone every star except Sirius (magnitude —1.7). Thereafter it slowly declined to the sixth magnitude and since 1869 has fluctuated between the sixth and seventh. These observed changes point to a great collision in 1751 and a smaller one in 1838. The smaller collision may be compared to the fall of the Earth into the Sun, which would develop heat sufficient to maintain solar radiation during 100 years. From the older observations it appears probable that the star suffered at least one earlier collision.

Another star of this type is Mira, or Omicron Ceti, which was the first star to be recognized as a variable, having been discovered August 13, 1596, by David Fabricius and described minutely by a Dutch astronomer, Phocylides Holwarda (1618-1651), in 1639. In 1667 its period of about eleven months was fixed by Ismael Boulliau, or Bullialdus (1605-1694), altho it was found that its fluctuations varied considerably. It was described in 1780 by Herschel, who had observed it in 1779, when it was nearly as bright as Aldebaran. Four days later the star was invisible even through his telescope. The maximum brightness of this star varies from the first to the fifth magnitude. At the minimum it falls below the sixth magnitude, becoming invisible to the naked eye, and occasionally below the ninth, so that at its maximum it has 1,000 times the luminosity of its minimum appearance. The spectrum of the star indicates that it is surrounded by three nebulous envelopes. The innermost of the surrounding envelopes is uniformly distributed and the others form a ring with two points of maximum density corresponding with the traces of two eruptive streams. This ring revolves in 22 months and has a linear velocity or rotational period of 14.6 miles per second. Hence it follows that the diameter of the ring is 1.45 times that of the Earth's orbit and that the mass of the central stars is slightly less than that of the Sun. Mira Ceti is typical of most of the variable stars in that they are red and give continuous spectra crossed by dark bands and bright hydrogen lines.

The third class of variable stars comprise those of irregular period, which differ from the so-called "new stars" in that they recur at more or less regular intervals of a number of years. These are, for the most part, red stars, altho there are others that fade away and are even lost from telescopic vision, tho once seen with the unaided eye. In some cases they have been associated with faint nebulosities.

Typical of the fourth class of variables is the star Beta Lyræ. Stars of this class have a short period measured by hours and days, and their variability is considerably due to eclipses by darker companions, tho both are self-luminous. As they have a white or yellow color, dust rings in their neighborhood are believed to play an important

part in their phenomena, tho less so than in the rays of the red star Mira.

As typical of the fifth class, composed of variables that change with almost absolute regularity, Algol, or Beta Persei, may be cited. This star's variability was first noted by Geminiano Montanari (1632-1687) in 1669, but it was more than a century later (in 1783) when John Goodricke (1764-1786), a deaf-and-dumb astronomer, detected the regularity of these changes and fixed their period at very nearly 2 d. 20 h. 49 m. Algol at its minimum luminosity gives about one-quarter as much light as when brightest, and the change from the first state to the second is effected in about ten hours. The Algol type of stars, including about 25 variables, are white in color and are characterized by a short period, which in most cases is less than five days. The change in intensity of light was first accounted for by Prof. E. C. Pickering as due to a second or dark star which travels about its primary, eclipsing it at various times. As the dark star begins to eclipse the brighter, the light diminishes until the time of greatest obscuration is reached, after which the normal value is attained. Pickering's theory for Algol, which normally is a star of the second magnitude, was demonstrated to be true by Vogel at the Potsdam Observatory in 1889. Therefore it is two stars, or a "spectroscopic binary."

Galileo and subsequent observers noticed that in many instances stars which appeared to the naked eye as single really were double. When these stars were separated under a high magnifying power it was found that they varied in distance, magnitude and color. Thus, if two stars are almost in the same line of sight, they will appear to the observer to be very closely related, altho one of the pair may be much nearer to him than the other and their proximity merely accidental. Such a pair of stars is known as a "double star," or an "optical double," and is to be distinguished from a pair of stars at approximately the same distance from the Earth, but so affiliated that they revolve about a common center of gravity. In other words, their relative positions would resemble those of the Moon and the Earth. When thus paired the combination is termed a binary system. The discovery of binary stars was first made by Sir William Herschel. He discovered that there were changes in the relative positions of the two stars which obviously were not connected with the motion of the Earth, but indicated an actual circling movement of the bodies themselves under a mutual attraction. He found that there was a regular progressive change in their motion which indicated that one of the stars was slowly describing a regular orbit around the other. Indeed, it seemed that gravitation had its effect beyond the solar system, as the orbit of each of such a pair of stars was found to be an ellipse with the common center of gravity at the focus. That is, the stars

were moving in two ellipses which were precisely similar, except that the one described by the smaller star was larger than the other in inverse proportion to the star's mass. While Herschel was the first actually to see such binary stars, yet their existence had been deemed probable by the Rev. John Michell, who lived a short time before the great observer.

Not only are there double stars to the number of 10,000, but triple and quadruple stars and even multiple stars in a single system. The distances between these stars generally amount to from 30″ to ¼″, as double stars nearer than the latter figure can be separated by only the most powerful telescopes. But the spectroscope enables stars much closer together to be resolved, and in fact the important class known as spectroscopic binaries previously referred to can be studied and their physical and optical properties determined by elaborate measurements. Thus Polaris, which in a moderate-sized telescope appears as a double star, including one of less than the second and one of less than the ninth magnitude, is really quite complex, for the brighter star revealed by the spectroscope has three stars very close together and all in circulation about one another. Again, in the case of binaries a spectrum with two sets of lines is seen in the spectroscope. With the telescope the image is single, but nothing can explain the double spectrum except the existence of two separate bodies. Accordingly, connected pairs of stars such as these are known as spectroscopic binaries. Often they make up a system of double stars visible in the telescope. Such an example would be Mizar, in the handle of the Plow, which, seen with a small telescope, appears as a double star, one of its components being white and the other greenish. In reality these two stars are situated so distant from each other that from one of them the other would appear merely as an ordinary bright star. But the telescope shows that the brighter of these stars is again a binary system of two huge suns, revolving around each other in a period of about 20 days.

Powerful spectroscopes now are able not only to resolve what appears as one point into two, but to detect motions of the two suns around their gravitation center. This has been simply explained by Prof. Larkin. He states that by the application of Doppler's principle "the times of revolution can be observed, and when the distant suns have a sensible parallax the distance between them can be determined in miles. With time and distance known, velocities in their orbits follow at once. Then with velocity and distance the mass of both can be computed—that is, both suns can be 'weighed' in terms of the mass of our Sun. For it is known from the laws of gravity and motion how much matter is required at any given distance and velocity to set up centrifugal tendency equal and opposite to gravitation.

"The Doppler principle applied to the discovery of binaries is shown

in the diagram, where S is a sun, far and away to one side of the center of the orbit of its companion, as shown in four positions, A, C,

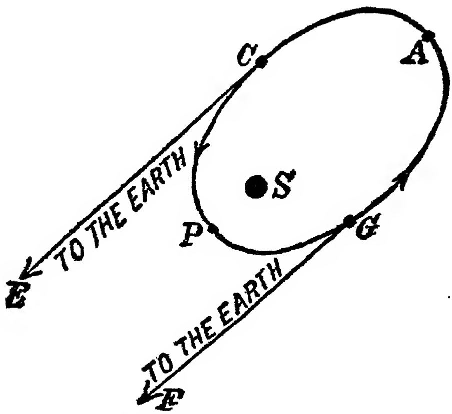


Fig. 43 —A BINARY STAR.

In this diagram S. is the place of the more massive sun, far and away to one side of the center of the orbit. The orbit and four portions of the revolving sun are represented by A., C., P., G. The two parallel lines, CE. and GF., point toward the earth. When the moving sun is at G., coming toward the earth, a line in the spectrum will shift toward the violet; and when at G., going away from the Earth, the line will move toward the red.

P, G. As seen from the Earth when at G, the flying sun will send fewer waves per second into the spectroscope and the Fraunhofer lines will shift toward the red. The point A is apastron and P periastron. The velocity of the revolving sun at P in its orbit is enormous, while the light and heat of S are intolerable to the people on any planet revolving around the sun P. For if either sun has a retinue of worlds like the Earth, with inhabitants, their changes of climate are extreme. While the flying sun is moving from A through C and around to P, the huge sun S rapidly increases its apparent diameter and also its light and heat. After passing C in the direction of the arrows, S must look like a blazing globe in skies of incandescent brass. In the revolution of a planet around either sun it would move in between them; there would be no night; the world and its people would be between two white-hot suns; life would expire. But if by chance a few of the inhabitants survive the passage through P, they would freeze when their sun reached the distant point A." Therefore all binaries having great eccentricity of orbits are utterly worthless for support of life on their planets if they have any. All planets are in-

visible from space, whence it follows that the inhabitants of stellar spaces have not heard of the Earth.

"Let us try Kepler's third law on a binary.

"Suppose an astrophysicist on this speck of dust, the Earth, far away in the direction of the arrows, say 100 or 200 trillion miles—it makes no difference which, provided light from the stars reaches the Earth in quantity sufficient to form a spectrum whose lines can be measured—wishes to find how much matter the two suns in the diagram contain. He sets the telespectroscope on the pair, night after night, and measures with extreme accuracy the shifting of the lines, now toward the red and then the violet. He does not see the stars in the instrument, but their spectra only—tiny delicate and beautiful bands made up of a few colors and black bands. But he watches the lines with great care when the moving sun is at C and G and measures their displacement with the micrometer. By repeated observations he finally learns a thing of vast import, the speed of the Sun's revolution in its orbit, and this entirely by means of the known relation between shifting of spectral lines and the speeds of the flying sun at times of approach and recession. And by direct observation he notes the time of one revolution. He multiplies velocities per second by the number of seconds and thus finds the circumference and radius of the orbit. He at once knows how many times farther apart the two suns are than our Sun and Earth. Then it becomes simple arithmetic to apply Kepler's law and find mass."

The distribution of the stars in the heavens seemed to the ancients to be fairly even on the whole. It was noted, however, that there was a long, relatively thin segment of space extending across the sky in which the stars appeared more numerous than elsewhere, and on account of its brilliancy this was termed the "Milky Way." Aristotle discusses it among other astronomical phenomena, and Greek astronomers looked upon it as a great circle of the celestial sphere. From those days to the present no satisfactory explanation has been offered for the existence of such a segment with the Earth apparently at its center, nor indeed for any of its characteristic peculiarities of aspect and its relationship to the stellar universe. Galileo, with his telescope, found that portions of the Milky Way consisted of multitudes of faint stars clustered together. It was recognized that the stars in the heavens were more and more closely massed as the Milky Way was approached.

With the realization that all stars were not at the same distance, there naturally followed speculation as regards their arrangement and distribution. The first positive contribution to the various theories and the apparent distribution of the stars in space came from Thomas Wright, of Durham (1711-1786), published in his "Theory of the Universe" (1750). This theory is of interest, not so much in

its original form as propounded by Wright, but for the fact that it was taken up five years later by the great philosopher, Kant, and by him developed in philosophically explaining the origin of the universe. Furthermore, in the hands of Sir William Herschel it became an important astronomical theory which received serious consideration for many years. Herschel's hypothesis was that the space occupied by the stars resembled in form a thick disk or "grindstone," close to the central part of which the solar system was situated. When such a disk was looked through lengthwise more stars were seen naturally than when it was looked through breadthwise. But at the same time there were vacant spaces or holes in the groundwork of the Milky Way, so that we can apparently see through the collection of stars. These holes or clefts are difficult to explain.

The Milky Way has been described by Prof. George C. Comstock as "a belt approximately following a great circle of the sky, but broad and diffuse throughout one-half of its course, while relatively narrow and well defined on the opposite side. The broad half of the belt is cleft in two by a dark lane running along its axis, and in addition contains numerous rifts and holes, from which the narrow half is relatively free. The number of stars per unit area of the sky is a maximum in the Milky Way and diminishes progressively on either hand, while the inverse relation is true for the nebulæ, their frequency increasing with increasing distance from the Milky Way."

But even the most superficial observer is forced to the conclusion that the stellar system is of limited extent and does not extend to an infinite distance. For if stars and suns exist through an unlimited space, their luminous radiations, which do not suffer in intensity in their passage through the ether, would reach the known universe with little diminution and the entire heavens would always blaze with light. That such is not the case is known from experience and from the fact that the combined illumination furnished by all the stars is only about one-hundredth part of that obtained from the full Moon. The theory has been advanced that the dark holes in the Milky Way, "coal sacks" as they have been termed, consist merely of dark stars or extinguished suns, such as the one we have seen occasions the eclipse of Algol. But this was disputed by the late Professor Newcomb, who says that there is no evidence that the light from the stars in the Milky Way, which are apparently the most distant bodies visible from the Earth, can be intercepted by dark bodies or dark matter, and that the stars are seen just as they are distributed in space. Furthermore, recent photographic work indicates that there is a limit to stellar distribution and that there is "a darkness behind the stars" which long exposure and powerful instruments cannot pierce.

The problem is one of striking immensity. Prof. E. C. Pickering speaks of the distribution of the stars and the constitution of the

stellar universe as perhaps the greatest problem in astronomy. In a recent discussion he remarks: "No one can look at the heavens and see such clusters as the Pleiades, Hyades and Coma Berenices without being convinced that the distribution is not due to chance. This view is strengthened by the clusters and doubles seen in even a small telescope. We also see at once that the stars must be of different sizes and that the faint stars are not necessarily the most distant. If the number of stars were infinite and distributed according to the laws of chance throughout infinite and empty space, the background of the sky would be as bright as the surface of the Sun. This is far from being the case. While we can thus draw general conclusions, but little definite information can be obtained without accurate quantitative measures, and this is one of the greatest objects of stellar photometry. If we consider two spheres, with the Sun as common center and one having ten times the radius of the other, the volume of the first will be one thousand times as great as that of the second. It will, therefore, contain a thousand times as many stars. But the most distant stars in the first sphere would be ten times as far off as those in the second sphere, and accordingly if equally bright would appear to have only one-hundredth part of the apparent brightness. Expressed in stellar magnitudes, they would be five magnitudes fainter. In reality the total number of stars of the fifth magnitude and brightness is about 1,500, of the tenth magnitude 373,000, instead of 1,500,000 as we should expect. An absorbing medium in space which would dim the light of the more distant stars is a possible explanation, but this hypothesis does not agree with the actual figures. An examination of the number of adjacent stars shows that it is far in excess of what would be expected if the stars were distributed by chance. Of the three thousand double stars in the "Mensuræ Micrometricæ," the number of stars optically double, or of those which happen to be in line, according to the theory of probabilities, is only about forty. This fact should be recognized in any conclusion regarding the motions of the fixed stars, based upon measures of their position with regard to adjacent bright stars."

CHAPTER XXV

NEBULÆ AND STAR CLUSTERS

NEBULÆ are masses of diffused shining gas which are scattered through space and which undoubtedly consist of the matter out of which stars have been and are being formed. They differ from star clusters in that the highest powered telescopes yet constructed are unable to resolve them into separate component stars, yet without doubt star clusters are evolved from nebulæ and their connection is most intimate. For the first record of a nebula we go back to Huygens (1629-1695) and find in his "System Saturnium" not only a description but a rough drawing. The description is of the nebula Orion and is as follows: "There is one phenomenon among the fixed stars worthy of mention which, so far as I know, has hitherto been noticed by no one, and, indeed, cannot be well observed except with large telescopes. In the sword of Orion are three stars quite close together. In 1656, as I chanced to be viewing the middle one of these with the telescope, instead of a single star twelve showed themselves (a not uncommon circumstance). Three of them almost touched one another, and, with four others, shone through a nebula, so that the space around them seemed far brighter than the rest of the heavens, which was entirely clear, and appeared quite black, the effect being that of an opening in the sky, through which a brighter region was visible."

The work thus inaugurated by Huygens for some reason or other did not seem to attract the attention of astronomers for many years, altho Lacaille, while at the Cape of Good Hope, 1750-1754, observed and described 42 nebulæ, nebular stars and star clusters, and altho Charles Messier (1730-1817), who devoted himself to the detection of comets, found he was liable to mistake nebulæ for comets, and recorded in 1781 the position of 103 of the former. In the meantime, in 1755 Immanuel Kant, the famous philosopher, advanced the theory on purely theoretical and speculative grounds that a single nebula or star cluster was an assemblage of stars, comparable in magnitude and structure with the aggregation which we now term the Milky Way and the other separate stars which can be seen. According to this theory, the Sun would be but one star of a cluster and every nebula a system of the same order. This was known as the "island universe" theory and was first accepted by Sir William Herschel.

In the course of his indefatigable investigation of the stars with his large telescopes Herschel inaugurated a systematic study of the nebulæ and star clusters. Altho he found it difficult to draw a line between neublæ and star clusters, yet he was able to state positively and correctly that they were not identical. Herschel noted the position of each nebula and its general appearance and marked the positions on a star map. He published catalogues, the first of which, prepared in 1786, contained 1,000 nebulæ and clusters, the second in 1789, of about the same extent, and a third in 1802, comprizing 500. Herschel's observations of nebulæ enabled him to note their differences in brightness and apparent structure so that he could divide them into eight classes. In 1786 he published the following interesting account of the varieties in form which he had observed:

"I have seen double and treble nebulæ, variously arranged; large ones with small, seeming attendants; narrow but much extended, lucid nebulæ or bright dashes; some of the shape of a fan resembling an electric brush, issuing from a lucid point; others of the cometic shape, with a seeming nucleus in the center; or like cloudy stars, surrounded with a nebulous atmosphere; a different sort again contain a nebulosity of the milky kind, like that wonderful inexplicable phenomenon about θ Orionis; while others shine with a fainter mottled kind of light, which denotes their being resolvable into stars."

Herschel's great problem was to determine the relation between nebulæ and star clusters. Often the difference between the two was made apparent only by the use of a telescope of sufficient power to resolve a bright glow in the heavens into clusters of stars. But at the same time there were bright places that still remained nebulous. Hence Herschel wrote: "Nebulæ can be selected so that an insensible gradation shall take place from a coarse cluster like the Pleiades down to a milky nebulosity like that in Orion, every intermediate step being represented." To Herschel it seemed that the power of the telescope was the important consideration, and the gradation mentioned, he writes, "tends to confirm the hypothesis that all are composed of stars more or less remote."

As Herschel progressed with his investigations the views of other astronomers, as well as those first entertained by him, did not seem tenable. By 1791 he reached the point of view that in certain cases at least the nebulæ were essentially different from star clusters. Referring to a certain nebulous star, he wrote: "Cast your eye on this cloudy star and the result will be no less decisive. . . . Your judgment, I may venture to say, will be that the nebulosity about the star is not of a starry nature." Herschel reasoned that if the phenomenon were due to an aggregation of far-distant stars there must be one central star of extraordinary dimensions or that something radically different, such as "a shining fluid of a nature

totally unknown to us," must be called upon to explain the appearance. His observations proved that an individual nebula was usually surrounded by a region of the sky comparatively free from stars, and that where clusters were common near the Milky Way nebulæ incapable of resolution were scarce, but were crowded together in parts of the sky most remote from this region. In short, Herschel believed that nebulæ and clusters were external "universes," and he early believed that both were objects of the same kind at different stages of development, the result of a "clustering power" working to convert a diffused nebula into a brighter and more condensed body, thus indicating the process of evolution or age.

Berry, in his "Short History of Astronomy," to which we are largely indebted for this record of Herschel's work in the nebulæ, thus summarizes Herschel's last views of this important phenomenon:

"His change of opinion in 1791 as to the nature of nebulæ led to a corresponding modification of his views of this process of condensation. Of the star already referred to he remarked that its nebulous envelope 'was more fit to produce a star by its condensation than to depend upon the star for its existence.' In 1811 and 1814 he published a complete theory of a possible process whereby the shining fluid constituting a diffused nebula might gradually condense—the denser portions of it being centers of attraction—first into a denser nebula or compressed star cluster, then into one or more nebulous stars, lastly into a single star or group of stars. Every supposed stage in this process was abundantly illustrated from the records of actual nebulæ and clusters which he had observed.

"In the latter paper he also for the first time recognized that the clusters in and near the Milky Way really belonged to it and were not independent systems that happened to lie in the same direction as seen by us."

Herschel's observations were utilized by Laplace, who was engaged in evolving a theory to explain the evolution of the universe. While his nebular hypothesis in its relation to other theories and systems will be discussed more fully in the following chapter, yet in this connection it is desirable to explain how Laplace was able to fit the results of Herschel's observations to his theory. Laplace had inferred that the planets and their satellites must have been derived from some common source, and he suggested that either they might have been condensed from a body and be regarded as the sun with a vast atmosphere filling the space now occupied by the solar system or that they represented the results of condensation of a fluid mass which now possesssed a more or less condensed central nucleus which at one time was not in existence. The nebulæ of Herschel accordingly suggested to Laplace a suitable fluid mass from which a solar system could have been condensed, and, furthermore, the evolution of the fixed

stars could be explained on a similar basis. This ingenious theory of Laplace's was rather a scientific speculation than an accurate conclusion founded on data he had himself observed. As a theory, whether accepted or not, it has proved of the most vital importance to science.

John Frederick William Herschel (1792-1871) published a catalogue (1833) of about 2,500 nebulæ, of which some 500 were new and 2,000 were his father's, a few being due to other observers, and later reobserved about 500 known nebulæ while at the Cape of Good Hope (1833-1838), including the nebulæ surrounding the variable star Eta Argus and the wonderful collection of nebulæ, clusters and stars known as the Nebuculæ or Magellanic Clouds. In 1864 Herschel was able to present to the Royal Society a valuable catalogue of all known nebulæ and clusters, amounting to 5,079. Later this great catalogue, which contained a condensed description of each body, was superseded by Dr. Dreyer's general catalogue, which was based upon it, and contained 7,840 nebulæ and clusters known up to the end of 1887. A supplementary list subsequently published by the same authority contained 1,529 entries of discoveries made between 1888 and 1894. Hence the two Herschels are responsible for more than half of the total number of nebulæ and star clusters now known to astronomers.

Sir John Herschel was of the opinion that no nebula existed that could not be resolved into a group of stars if a sufficiently powerful telescope were employed. With the various large reflectors in use during the first half of the nineteenth century, gradually a limit was reached. Some nebulæ remained unresolved, which led to the conclusion either that still more powerful instruments were required or that they were in their nature unresolvable. Herbert Spencer, believing that the principle of evolution must operate universally and that the stars must be formed from nebulæ, ventured to oppose the astronomers in their belief that only telescopic power was needed to resolve nebulæ into groups of stars. In fact, from the point of view of the astronomer the study of nebulæ had almost ceased when a new method was introduced which served not only to throw a vast amount of light on the question but practically to turn astronomical research into new channels.

In 1864 the first positive clue to the nature of nebulæ was gained by Sir William Huggins, when he was able to obtain with the spectroscope a characteristic spectrum of the planetary nebulæ in Draco. This discovery was interestingly described by Sir William in the following account, recorded in the "Publications of the Tulse Hill Observatory," Vol. I:

"On the evening of August 29, 1864, I directed the spectroscope for the first time to a planetary nebula in Draco. I looked into the spec-

troscope. No spectrum such as I had expected! A single bright line only! At first I suspected some displacement of the prism and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. After passing through the two prisms it remained concentrated into a single bright line, having a width corresponding to the width of the slit and occupying in the instrument a position at that part of the spectrum to which its light belongs in refrangibility. A little closer looking showed two other bright lines on the side toward the blue, all three lines being separated by intervals relatively dark. The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas."

This discovery marked a new era in astronomical progress. Its importance was at once appreciated, and the ability of the spectroscope to distinguish between a glowing gas and a star-like mass of partially condensed vapors solved the problem that had so seriously concerned the elder Herschel and immediately brought the spectroscope forward as the chief instrument that must be employed in the larger problem of the evolution of the stars in the universe. It was at once apparent that these amorphous nebulæ might supply the material from which the stars were formed and that the process was one of evolution and possibly mere condensation.

What the spectroscope actually has accomplished for research on the nature of the nebulæ was excellently summed up by Sir David Gill in his presidential address before the British Association for the Advancement of Science at Leicester (1907). "Huggins' spectroscope," he said, "has shown that many nebulæ are not stars at all; that many well-condensed nebulæ, as well as vast patches of nebulous light in the sky, are but inchoate masses of luminous gas. Evidence upon evidence has accumulated to show that such nebulæ consist of the matter out of which stars—*i.e.*, suns—have been and are being evolved. The different types of star spectra form such a complete and gradual sequence (from simple spectra resembling those of nebulæ onward through types of gradually increasing complexity) as to suggest that we have before us, written in the cryptograms of these spectra, the complete story of the evolution of suns from the inchoate nebula onward to the most active sun (like our own) and then downward to the almost heatless and invisible ball. The period during which human life has existed upon our globe is probably too short—even if our first parents had begun the work—to afford observational proof of such a cycle of change in any particular star; but the fact of such evolution, with the evidence before us, can hardly be doubted."

After the spectroscope, photography has been found a most valuable method of nebular research, and many discoveries have been recorded through its assistance. It will be appreciated readily that an impression left by visual observation in a matter of this kind would necessarily be very vague, and, furthermore, that the record on a sensitive plate by long exposure would show far more detail than even the eye of the observer can perceive. Accordingly all the great observatories of the world, particularly those equipped with good reflecting telescopes, have been at work on nebular photographs since about 1880, tho it was not until 1883 that the first really excellent pictures were obtained.

It was early seen that the light of nebulæ was strongly photographic, that it was really more actinic than visual. A photograph with a long exposure showed the Merope nebulæ in the Pleiades just as the best observers had drawn it, and at the same time filled the entire group of stars with an entangling system of nebulous matter which seemed to bind together the different stars of the group with misty wreaths and streams of filmy light, nearly all of which detail is entirely beyond the keenest vision and the most powerful telescope.

After Sir William Huggins with his spectroscope had endeavored in vain to determine the radical movement of nebulæ, Professor James E. Keeler repeated the attempt at Lick Observatory in 1890-91 and achieved great success. Ten planetary nebulæ showed satisfactory evidence of line-of-sight motion, one of which, the well-known greenish globe in Draco, was found to be moving toward the Earth at a rate of 40 miles a second, while the Orion nebula was receding at a rate of 11 miles. Keeler's work demonstrated that no longer should nebular fixity be loked upon as a fact and that nebulæ have a motion which can be studied. Again the sensitive plate had scored a triumph.

The study of nebulæ has led to their classification under various heads into spiral, planetary, ring and irregular nebulæ. The first spiral nebula was discovered by Lord Rosse (1800-1867) with his great 6-foot reflecting telescope, which was mounted at Parsontown, Ireland. A typical spiral nebula consists of a central disk-shaped portion or nucleus, with two long, curved arms projecting from opposite sides, giving the effect of rapid rotary movement and slightly suggesting the familiar "pin-wheel" of firework displays. The chief characteristic of the spiral nebulæ is their white color as compared with the greenish tinge of other types. Furthermore, they are more numerous than all other types combined, it having been estimated by the late Professor Keeler, of Lick Observatory, that at least 120,000 of these spirals were within the grasp of the Crossley reflector of that institution, while Professor Perrine, at the same observatory, increases the estimate to half a million and believes that with a more sensitive photo-

graphic plate and a long exposure over a million could be obtained. According to their spectra, they are largely in a solid or liquid condition, but are of a tenuous character and very transparent, so that it is inferred that they consist of vast swarms of incandescent solid or liquid material, surrounded by gaseous material. The nebula in Andromeda is the greatest spiral known. Its diameter is more than 500,000 times the distance from the Earth to the Sun, or 8 light-years. It is visible to the naked eye and is second only to that of Orion in size and splendor. It has frequently been mistaken for a comet. If it were one-twenty-millionth as condensed as the Sun it would attract the Earth as much as the Sun does. The extreme rarity or tenuity of nebulæ is evident from the fact that there is no evidence that we have the slightest disturbance of the motions of even those stars nearest to them.

Planetary nebulæ consist of small, round elliptical disks of light, appearing much like the planets. Hence their name. In the spectra of these nebulæ are found bright lines in the green portion, which are characteristic of no terrestrial substance. Accordingly a hypothetical gas, "nebulium," was assumed by Sir William Huggins (1868) to correspond with these lines. At first Lockyer in England believed that the green line of nebulium was due to magnesium oxide, but this was entirely disproved by Keeler. The nuclei of planetary nebulæ are often bright, as if to indicate that condensation is taking place at their centers. The smaller and even brighter nebulæ are possibly representative of a final stage of planetary nebulæ, or else they become stars and are then known as steller nebulæ.

A few ring nebulæ are found which have an annular shape, the center of the ring being filled with nebulous light. Hence it may be assumed that the ring nebulæ are brighter around the circumference than at the center. The most striking and typical ring nebula is that of Lyra.

The Orion nebula, which, as we have said, is the largest of nebulæ, is typical of irregular nebulæ and is also one of the most beautiful bodies in the heavens. It is situated in the center of the "sword" of Orion and from the time of Sir William Huggins has been studied extensively with the spectroscope. The bright lines of nebulium and hydrogen are noted in the spectrum, which shows conclusively that it is a mass of glowing gas. This nebula represents a vast amount of material, and if the theory that the condensation of such material produces stars needs proof, here obviously are the sources of many suns in a very rough stage of development.

The distribution of nebulæ, as Herschel noted, is quite the reverse of that of the stars. They are less numerous in the Milky Way, increasing in number as we go from it in any direction. A speculative

explanation advanced is that the two regions of maximum nebulæ represent places where they have not yet condensed into stars.

Not only the spectroscopic evidence of bright lines, but the aspect of nebulæ themselves shows that they are transparent through and through. This is remarkable when taken in connection with their inconceivable size. Leaving out the large diffused nebulæ which we have mentioned, these objects are frequently several minutes in diameter. Of their distance we know nothing, except that they are probably situated in the distant stellar regions. Their parallax can be but a small fraction of a second. We shall probably not err greatly in excess if we assume that it varies between one-hundredth and one-tenth of a second. To assign this parallax is the same thing as saying that at the distance of nebulæ the dimensions of the Earth's orbit would show a diameter which might range between one-fiftieth and one-fifth of a second, while that of Neptume would be more or less than one second. Great numbers of nebulæ are, therefore, thousands of times the dimensions of the Earth's orbit, and probably most of them are thousands of times the dimensions of the whole solar system. That they should be completely transparent through such enormous dimensions shows their extreme tenuity. Were our solar system placed in the midst of one of them, it is probable that we should not be able to find any evidence of its existence.

Considerably less conspicuous than the constellations, but composed of a far greater number of stars, are various clusters and systems which often contain several thousand individual members. It was the telescope of Galileo that first made possible the study of these clusters, for he saw in the Pleiades 36 stars where the ordinary eye could distinguish but six. In other parts of the heavens, as in portions of the Milky Way, he could observe clustered together multitudes of fine stars, and in Præsepe, in the constellation of the Crab, he was able to count 40 stars. With additional telescopic power further clusters were noted, and Halley (1656-1742), for example, discovered a great star cluster in Hercules, which, now known as Messier 13, later derived its name from the catalogue of the famous French astronomer and comet hunter, Messier (1730-1817). But it was Herschel, with his high-power telescope and his keen powers of observation, who was able to give the subject further research, and he became, as we have seen, greatly interested in the distinction between nebulæ and star clusters. Herschel found that many of the nebulæ recorded by Messier could be resolved and he immediately pushed observation in this field.

The most recent theory of the formation of star clusters is due to Arrhenius, who states in "Worlds in the Making" that most of the clusters are found in the neighborhood of the Milky Way, where also

the visible stars are usually crowded and where almost every year some new star is discovered. It is in this region that collisions between stellar bodies are most likely to occur and where gaseous nebulæ would be produced. "The nebulæ," Arrhenius goes on to state, "which are produced by collisions between two suns, are soon crossed by migrating celestial bodies, such as meteorites or comets, which there occur in large numbers; by the condensing action of these intruders they are then transformed into star clusters. In parts of the heavens where stars are relatively sparse (at a great distance from the Milky Way) most of the nebulæ observed exhibit stellar spectra. They are nothing but star clusters so far removed from us that the separate stars can no longer be distinguished. That single stars and gaseous nebulæ are so rarely perceived in these regions is no doubt due to their great distance."

About 100 star clusters are known, and they comprise either groups of the brighter stars or densely packed gatherings where a large number of faint stars, as a rule between the twelfth and sixteenth magnitudes, are collected. Of the first class the Pleiades are typical and are perhaps the best known, tho the Hyades, Coma Berenices, Præsepe in Cancer and Orion are also representatives of this form of cluster. The Pleiades contain seven visible bright stars of about the fourth magnitude and cover nearly three square degrees, in addition to which there are a large number of fainter stars, some of which were first seen by Galileo. Of these 53 have been examined and their motions determined. Nearly 2,000 fainter stars are included in the cluster. They are less numerous here than in most parts of the sky and even in the immediate neighborhood. The Pleiades, it must be remembered, are distant 267 light-years, at which distance the Sun would appear to the Earth as a star of the ninth magnitude; and while these perhaps appear as a cluster, they are really something like one-hundredth as far from each other as the group, is from us, or two or three light-years. In 1859 Wilhelm Temple discovered a faint nebulosity near Merope, one of the brighter stars of the group, and on November 14, 1890, Barnard at the Lick Observatory noticed a second nebulous companion to this star and reached the opinion that the whole cluster contained a number of faint nebulosities. This opinion was confirmed by photographic observations, which showed that the entire group was embedded in a nebulous matrix which extended over a large section of the heavens and indicated that the stars, many of which, as brilliant as our own Sun, cannot be seen without high-power telescopes, are intimately related to their origin and in their evolution. In Coma Berenices, containing seven fifth-magnitude stars visible to the naked eye and lying east, south or west of the zenith on a spring or summer eve-

ning, there is an unusual grouping of lucid stars within a small area and in addition a large number of fainter stars. The cluster Præsepe, in the constellation of Cancer, when seen by the naked eye, appears as a patch of nebulous light, but is really a condensed group of stars of which the brightest are of the seventh magnitude or just beyond the range of visibility. An interesting cluster is contained in Orion, where a circle 20 degrees in diameter, comprising the brightest stars of the constellation, was found by the late Professor Newcomb to contain 80 stars of magnitude 6.3. Of these six are of the first or second magnitude, leaving 74 from the third to the sixth. But this remarkable collection of bright stars has no unusual number of faint stars associated with it, and the conclusion reached is that the agglomeration of the brighter stars into clusters does not extend to the fainter stars where it is noticeable to the eye.

Globular clusters containing a vast number of stars closely packed together are seen in the constellation of Hercules. It contains over 5,000 stars and is so brilliant that the naked eye can see it as a patch of light in the heavens, tho the telescope of course can resolve it into a number of individual stars. In fact, 5,482 have been counted on a photograph taken at the Lick Observatory. Other clusters of this class are that of Omega Centauri in the southern heavens, which shows 5,000 more stars than the average star density of the region, and in the northern sky Canes Venatici and Pegasus. These globular clusters cover less space than the apparent diameter of the Moon, or less than one-half a degree, and the stars they contain vary from the twelfth to the sixteenth magnitudes. Their composition is a disputed point—whether the feeble appearance of the stars is due to great suns at immense distances or whether there is a large number of small bodies among which matter is faintly distributed. It is probable, however, that they are distant about 400 light-years. The clusters themselves have vast dimensions and the stars of which they are composed are separated by great intervals. For example, in a cluster containing 5,000 stars the average distance of one from another might be 30,000 times the distance of the Earth from the Sun, so that they can move freely without danger of collision. The law of gravitation does not require any greater velocity for them than is possessed by the average star. A number of the individual members of these clusters are variable, but the reason for this variability has not yet been explained.

The late Professor Newcomb says that "Perhaps the most important problem connected with clusters is the mutual gravitation of their component stars. Where thousands of stars are condensed into a space so small, what prevents them from all falling together into one confused mass? Are they really doing so and will they ultimately

form a single body? These are questions which can be satisfactorily answered only by centuries of observation. They must, therefore, be left to the astronomers of the future." To this Prof. Barnard answers simply. "The same laws doubtless keep the stars in the clusters from rushing to the center, that prevent the stars in our universe from doing the same thing; that is, the laws of gravitation and motion.

CHAPTER XXVI

THE MAKING OF THE WORLDS

The striking regularity and uniformity which prevails in the planetary system was a mystery to Newton. He was aware that the then known planets and satellites all move in the same direction, all nearly in the same plane—the ecliptic—and all in almost circular orbits. As Newton did not believe in any vortex movement, such as that suggested by Descartes, to carry the celestial bodies along with it, he could not understand this peculiar regularity, the less so because the comets, whose orbits seemed likewise to be dependent upon the attraction of the Sun, frequently did not at all move in the same direction as the planets. Without any justification, Newton drew the conclusion that the regularity of the planetary movements could not have any primal cause.

The first who seems to have aspired to such an explanation was Buffon, the ingenious author of the "Histoire Naturelle" (1745). From the outset he emphasized the extraordinary improbability that the inclination of the ecliptic to the plane of the planetary orbits would, by itself and merely owing to chance, never exceed 7½° or one-twenty-fourth of the largest possible inclination of 180°.

That point had already been accentuated by Bernoulli. The probability that this inclination is mere chance amounts for every single planet only to one-twenty-fourth. For the five then known planets taken altogether, the probability assumed the value of 24^{-5}, or one eight-millionth. They had to consider in addition that the satellites, so far as then known—namely, the five moons about Saturn, four about Jupiter, the one of the Earth and the ring of Saturn—were all moving in planes which deviated little from the ecliptic. A mechanical cause had to be found in explanation of these facts.

In order to explain the movement of the planets, Buffon supposed that they had resulted from a collision between the Sun and comets. Assuming that a small amount of the Sun's mass was knocked off, he fancied that as the result of such collisions planets and their moons were formed. The possibility of such an impact between a comet and the Sun seemed to him proved by the comet of 1680, whose orbit, Newton had calculated, passed the Sun's luminous surface at a distance of only one-third the solar radius, and on its return 600

years later would fall into the Sun. The fragments of the Sun formed from such a collision would not drop back into that body, but would fly off with a rotary motion in the same direction. The fragments which possessed the smallest density would attain the greatest velocity and would therefore be hurled farthest away from the Sun before their orbits began to curve. The enormous heat produced by the collision would probably render the planets liquid, but they would rapidly cool owing to their small size, tho remaining incandescent for longer or shorter periods. Thus to the Earth Buffon assigned a period of 75,000 years for cooling down to its actual temperature, for the Moon 16,000 years, for Jupiter 200,000 and for Saturn 131,000, while the Sun required ten times as long again as Jupiter. In passing through the atmosphere of the Sun after their separation the planets would absorb from it air and water from which seas would later on be condensed. This atmosphere would resemble that of the Earth, for, except that he thought the Sun was a solid incandescent body, Buffon regarded it as otherwise resembling the Earth in its essential characteristics. The Earth he considered had ceased to be incandescent because no air could penetrate into it to feed the internal fire. Yet at the same time he believed that only 2 per cent. of the terrestrial heat was due to the radiation from the Sun, the remainder being the Earth's own heat.

Buffon's theory was followed by that of Thomas Wright whose hypothesis of the evolution of the universe as well as the solar system, published in 1750, supplied an approximately scientific explanation of the whole sidereal universe. According to Wright, the solar system is but one of a vast number of such gravitating systems which form the Milky Way. These are arranged in a great double ring, forming a stratum or disk of stars which rotates about an axis perpendicular to its plane.

The ideas of Wright met with the approval of Immanuel Kant, who in 1755 explained his theory of the evolution of the solar system. According to him, cosmic space was empty, and the planets could not be carried through it by any vortices in the sense of Descartes. But, provided the planets had once been set in motion, no other impelling force was needed for them in this empty space. Why could it not be assumed that the vortex which had started these planets on their trajectories had once existed and disappeared afterward? Kant then states "that in the beginning all the matter which is now in the Sun, planets and in the comets must have been spread through the space in which these bodies now circulate." The attraction of the particles was directed toward the center of this mass of dust, where the Sun stands now. The material particles at once began to fall toward the center of the mass. Thus resulted movements in closed paths or circular orbits about the center. As the different bodies collided with one an-

other they eventually grouped themselves and moved in circular paths in the same direction about their common center. Some of the bodies which were falling toward the center would likewise assume the same movement and would cause the Sun to rotate about its axis in the same direction. Kant maintained that the central body would be specifically lighter than those nearer to it. In this respect he was in error, as we see in the case of the Earth and the Moon.

Kant advanced various explanations for such points as the deviation of the planetary orbits from circles and their inclination to the ecliptic, for the formation of Saturn's rings, for the interpretation of the deluge and other biblical facts. Finally he explained the extinction of the Sun, which, according to the view of that age, was a celestial body in the process of burning. The end of the Sun was destined to ensue from want of air and from accumulations of ashes. In this process of burning the Sun had lost its most volatile and finest particles, constituting the cloud of dust which he assumed to be the seat of the Zodiacal Light. Kant makes the significant observation that "the law concerning the extinction of the Sun includes a germ for the reunion of dispersed particles, even if the latter should have intermingled with the chaos." This is interesting as indicating that matter passed through a cycle of evolution, being now condensed into suns and now scattered into chaos, the idea partaking somewhat of that advanced centuries before by Democritus, who believed that matter was in constant motion and that the atoms were eternal and indestructible. In short, the cosmogony of Kant is typical of those theories which assume the planetary system to have originated from cosmic dust or from a collection of small meteorites. In more modern times ideas based on this hypothesis have been advanced by Nordenskiöld and Lockyer, while Sir George H. Darwin has devoted much thought to the mathematical consideration of such a theory.

Few philosophers or astronomers were in a better position to frame a basis for cosmical theory than Laplace, whose work in this field must be mentioned after that of Kant. At the end of his "Systeme du Monde" (1796) he advances a mechanical explanation of the evolution of the solar system, accompanying it, however, with the explanation that it had not been subjected to rigorous mathematical analysis and proof and was advanced in a more or less tenative way. Despite the hesitancy with which Laplace offered this contribution to cosmical theory, it soon secured wide consideration and was found acceptable as a fundamental basis to explain the origin and evolution of the universe. In fact, this nebular hypothesis was, without doubt, during the nineteenth century the guiding idea in cosmical philosophy as well as the philosophical basis underlying astronomy. The work itself has been likened very properly to that of Charles Darwin.

Laplace starts with the assumption of a glowing mass of gas which

from the very first was in vortex motion from right to left (as viewed from the north) about an axis passing though its center of gravity. "In its primitive assumed condition the Sun resembled those nebulæ which are shown by the telescope to be composed of a more or less brilliant nucleus surrounded by a nebulosity which is condensing upon the nucleus, transforming it into a star." The solar mass cannot have extended out indefinitely. Its limits were the points at which the centrifugal force due to its motion of rotation were balanced by the gravitation of its action. On cooling the nebulæ would contract, and in this contraction of the glowing mass of gas a gaseous disk would be split off when the centrifugal force of the rotating mass would be equal to the inwardly directed force of gravitation, so that the solar nebulæ were divided into rings of glowing gases which would rotate as a whole and cool down in a solid or liquid ring.

Laplace says: "It may be conceived that the endless variety in the temperature and density of the various parts of this great mass produced eccentricity of their orbits and deviation of their motion from the plane of its equator." Laplace mentions the presence of comets, which he states are strangers to the planetary system, as colliding with the planets during their process of formation and causing them to deviate, while other comets entering the solar system near the condensation of gaseous matter, so nearly completed, became retarded in their motion and were incorporated into the solar system.

His conclusion was as follows: "Whatever be the masses of the planets it is only owing to the circumstance that they all move in the same direction and in almost circular orbits, at small inclinations to one another, that the secular variations in their orbits are periodical and within narrow limits, and that the system therefore oscillates about a mean condition, from which it never deviates by more than an insignificant amount."

While Laplace's theory was open to critcism and objection at numerous points, yet it played a useful and remarkable part in the development of science. The Newtonian doctrine of the wonderful stability of the solar system was more firmly established and the permanence of the planetary system was guaranteed. While it was confined only to the solar system, yet the idea of the nebular hypothesis was readily applicable to the universe itself and formed what was long considered a satisfactory means of accounting for its origin and evolution.

In its mechanical aspect Laplace's idea of the segregation of small dust particles during the cooling of nebulæ and their aggregation by the condensation of gases into a ring or a single big mass was found physically impossible by later astronomers, notable among whom were Stockwell and Newcomb. There would result, on this hypothesis, a collection of small meteorites such as circulated in the Saturn rings, and the transformation of the Neptune belt into a planet would have

required no less than 120 million years. The retrograde movement of the moons of Uranus and Neptune and also that of the most remote moons of Saturn and Jupiter formed another serious objection to the thesis of Laplace.

The first important cosmical theory seriously to modify the nebular hypothesis of Laplace was that first presented on November 17, 1887, by Sir Norman Lockyer. This was known as the meteoritic hypothesis and in its more complete form was published in 1890. The fundamental principle involved in this theory was that "all self-luminous bodies in celestial space are composed either of swarms of meteorites or of masses of meteoritic vapor produced by heat." This theory was the result of spectroscopic studies. Lockyer claimed that the original nebulæ were composed of meteoric material or cosmical dust rather than gases. In other words, nebulæ were vast swarms of meteors and their light resulted from continual collisions between constituent particles. Such a collision might take place between two stars, shattering both and producing a vapor or vapor combined with meteoric fragments from which other stars might be derived. Thus a dark star might be transformed into a bright and glowing star and pass through successive changes until it was dissipated by some long-delayed collision. Lockyer assumed that the meteorites could be regarded as analogous to wandering molecules of gas moving indiscriminately in all directions and at widely different velocities. He believed that the heat produced by the collision already referred to would volatize certain constituents of the meteorites and render them luminous. These luminous materials would supply a spectrum, and the discussion of the properties of the spectra of nebula was an important consideration in Lockyer's work. In some respects this theory has been found untenable. The meteoritic hypothesis was never considered seriously as supplanting the fundamental ideas involved in Laplace's great generalization.

Sir George H. Darwin, whose work on the tides has had considerable bearing on cosmical theory, also discussed the physical and mathematical properties of the meteoritic swarm, and demonstrated that its behavior closely resembled that of a gas and that the meteorites would move about, colliding with one another in much the same fashion as the molecules of gas according to the kinetic theory. Darwin further demonstrated that when a mass was widely extended it would revolve as a solid. But such ideas as those of Lockyer and Darwin involved modifications of the nebular hypothesis rather than an overthrow.

At the very end of the nineteenth century F. R. Moulton and T. C. Chamberlin, of the University of Chicago, denied some of the fundamental ideas involved in the nebular hypothesis. Not only was their work destructive in that they advanced phenomena which the theory

of Laplace could not explain, but which were in fact controverted directly by observation, but they constructed a cosmical theory in which these elements were taken into consideration and in which, in large part, the conditions were met. The chief objections to the theory of Laplace, as stated by Professor Moulton, are as follows:

"1. The considerable mutual inclinations of the planes of the planetary orbits and the inclination of the plane of the Sun's equator to the general plane of the system are not to be expected on the basis of the ring theory.

"2. The eccentricities of the planetary orbits are not to be expected on the basis of the ring theory.

"3. The orbits of the planetoids contradict the ring theory.

"4. The rapid revolution of Phobos and of the particles of the inner ring of Saturn cannot be satisfactorily explained.

"5. The presence of light elements in the Earth is not to be expected.

"6. A series of rings could not have been left off.

"7. A ring could not have been condensed into a planet.

"8. The moment of momentum of the present system is less than 1/200 of that of the supposed initial nebula.

"9. The retrograde revolutions of the ninth satellite of Saturn and (probably) of the seventh satellite of Jupiter flatly contradict the theory."

Of these objections one of the most important is the question of the leaving off of the rings at certain intervals during the contraction of the nebulæ. On this point Professor Moulton writes in his "Introduction to Astronomy": "It is easy to overlook the fact that the postulated nebula must have been excessively rare. According to the hypotheses made, it must have been denser at its center than near its periphery. But if we suppose that it was homogeneous and that it reached out to Neptune's orbit, we find that its density was only 1/250,000,000 that of air at the sea level. Neptune's ring could not have been so dense as this, which is many times rarer than the best vacuum yet produced in our laboratories. Now a ring of such rarity would have had no cohesion and would not have separated except particle by particle. When the process was once started it seems that it should have been continuous instead of intermittent as the theory supposes. The theory postulates that when a ring was left behind, the nebula was made stable for a long period of contraction. Roche has attempted to show that rings of considerable dimensions would be abandoned at certain intervals, but his work on this point is far from conclusive. Every other writer on the subject has keenly felt this difficulty. Thus Faye, in his modification of the Laplacian theory, supposed that the whole nebula broke up into rings simultaneously.

"We may assume for the sake of argument," he says, "that rings are abandoned and inquire whether they will unite into planets or not. The matter of the ring would be very widely spread out and mutual gravitation of its parts would be very feeble. The appropriate investigation shows that the tidal forces coming from the interior mass would more strongly tend to scatter the material than its gravitation would to gather it together into a plane. Consequently a ring could not even start to condense into a planet. It would be something like a comet which becomes utterly dissipated by tidal forces.

"To give every possible advantage to the ring theory, we may assume that all the matter has been gathered into a planet except a ring of very small particles, and then ask ourselves whether this minute remainder will be brought to the planet. Investigation shows a strong probability that only that part of the ring which is within 60° of the planet could be brought on to it in any time however long. That is, if we assume that the process of formation of a planet out of a ring is almost finished, we find that it cannot complete itself. This shows the strong improbability that the assumed stage could ever have been reached by condensation from a more uniform ring."

Then it must be considered that the ninth satellite of Saturn and the seventh satellite of Jupiter revolve in a direction contrary to the other revolutions and rotations of the solar system, which would be an impossibility if the Laplacian doctrine were true. Finally, notwithstanding a careful and thoro study of nebulæ, developed by photography to a point of great refinement, there has been found no trace of a nebula which is in the course of breaking up into concentric rings. The spiral nebulæ, such as the theory propounded by Professors Chamberlin and Moulton required, are of the normal type of nebulæ, and it is this fact, brought out in the brilliant discoveries of Professor Keeler, that has largely produced the new theory which has been termed by its originators the "planetesimal theory."

This planetesimal hypothesis to-day is attracting widespread and favorable attention from many astronomers and geologists. While it explains the formation of the solar system and other systems, it does not eliminate the question of primitive matter, which doubtless must have been nebulous. While spiral nebulæ may have been formed by the collision or interaction of large suns, yet these in turn demand for their origin a similar occurrence, so that one is led rather strongly to the belief that the formation of systems of suns and worlds may be a continuous process.

The planetesimal hypothesis has been summarized in the following simple statement by Prof. James F. Kemp in the course of a lecture in which its application to the origin and development of the world is discussed. He writes: "Instead of a highly heated and subsequently cooled and solidified gaseous original, minute particles of matter, which

may have been molecules, are believed to have moved in orbits around a common center in a manner analogous to the solar system of to-day. In their evolution they became aggregated into larger bodies, such as the planets and the Earth, continuing in groups the motions and relations they possessed when individuals. As the mass gradually increased the pressure of the outer layers consolidated the core and by the mechanical changes involved produced those internal stores of heat with which we are familiar in volcanoes and in deep borings and mines. Vapors or liquids in the original cold particles are believed to have been gradually squeezed out by this pressure. The little particles are called planetesimals or diminutive planets.

"Like all attempts to formulate primeval conditions, the data of this new conception are partly matters of observation, partly assumptions. Speculation enters in a very large degree, and, as in the case of various and widely differing estimates of the age of the Earth based on assumed rates of cooling, once the data were provided, mathematical reasoning goes to a conclusion with unerring accuracy. But the correctness of the solution turns on the reliability of the original data, and where these are so largely assumptive the conclusions are from time to time subject to change. Yet we must have a starting point, and the striking contrasts of the older and later views cannot but impress every one who reflects upon them. The former postulates a highly heated original, the latter a cold one. The one begins with gaseous matter, the other with solid. The one draws upon an original but diminishing store of heat, the other develops heat continuously by mechanical processes. In many ways the two are diametrically opposed; yet some have raised the question whether, in order to obtain a swarm of separate cold particles, we must not in our thought go still farther back to a gaseous or nebulous source, and it is not clear that we have yet escaped the necessity of at least the essential features of the nebular hypothesis."

Whatever theory is studied or adopted, it is clear that the building of suns and the building of worlds is a process of evolution in which the original matter must undergo transformation. The process may be continuous and may extend through infinite time. The collision of suns may have produced nebulæ and these nebulæ in turn may gradually develop themselves into suns again. It seems reasonably certain that nebulæ are the stuff from which the stars are made. Of the many types of nebulæ the spiral forms are considered the more primitive. There is indeed evidence to show that even such apparently irregular nebulæ as that in Orion still preserve traces of original spiral formation.

Professor Dewar has experimentally proved that, at the low temperature prevailing in the outer regions of a nebula, it is one of the properties of a dust particle to attract and condense on its surface

whatever gas may be within its immediate vicinity. It may be safely assumed, therefore, that each particle of dust hurled out by the explosion of two colliding suns bears its charge of gas. That these gas-laden dust particles should collide with one another would follow from their motion and their excessive number, and that these particles should be cemented together by the film of liquid gases on their surfaces would in turn follow from the fact of their collision. Thus, in the course of centuries, large grains or aggregations of matter constituting meteorites are formed, which, by gravitational attraction, gather about them part of the remaining dust and gas. Stars, comets and meteorites from other systems will also wander into the nebula, attracting the gas and dust of the nebula. Evidence of this draining of a nebula by an immigrant star is to be found in many a constellation, notably in the Swan, where a distinct lane has been plowed through a nebula by an errant star. By this upbuilding of meteorites from colliding gas-laden dust particles and the concentration of nebular matter by bodies which have strayed into the nebula, the entire mass of gas and dust is converted in the lapse of ages into clusters of stars, slowly revolving about the central Sun in periods of thousands of years. Such star clusters are familiar objects in the heavens. They may be found in the Pleiades, in Pegasus and in other constellations.

Each star in a cluster may be regarded as either the center of a new solar system or as a new-born world—not a rock-bound, sea-swept world as yet, such as the Earth, but a glowing chaotic mass, an embryo which will cool and shrink as it cools and which will eventually chill into a solid sphere. The central Sun, because of its greater size, will blaze on for centuries after the clusters about it have congealed into planets. Because the shrinking and cooling are not of a year's nor even a century's duration, but are extended over millions of years, it is possible to study the various stages of the process in stars that have been formed from nebulæ at widely different epochs. The method of investigation bears some relation to the system devised by the evolutionists in tracing the development of life on this Earth. With the aid of fossils dug out of the Earth the paleontologist has ingeniously bound the living present to the dead past with the chain of evolution, and shown very convincingly how the creatures that now roam the Earth are inevitably linked with the extinct animals of prehistoric time. An analogous system of stellar classification, formulated by Prof. W. W. Campbell, throws not a little light on the ancestry of the myriad of stars whose rays pierce the heavens. Such a search indubitably points to nebulæ as the stuff of which worlds are fashioned.

In estimating the period which probably elapses before a star in a cluster will shrink into an incrusted world the color of the star's

light plays no small part. Red-hot iron is not nearly so hot as white-hot iron. The color of the molten metal gives the iron-founder a clue to its temperature. Similarly a star's temperature may be gaged by its tint. Since temperature, and therefore color, alter with age, it is possible to state in a rough way that red stars are the oldest of luminous bodies and that the orange, yellow and white stars follow in respective antiquity. Youngest and hottest of all are the bluish-white stars.

The spectroscope draws nicer distinctions than those which can be drawn by color alone. Professor Campbell has discovered from his study of stellar spectra that when the spectrum of a star is rich in the bright lines of the gases hydrogen and helium it is certain that the star in question is young. Indeed, the presence of nebulous masses about many stars in this stage of their evolution proves how true is Professor Campbell's conception. In the constellation of Orion, for example, is a nebula in which stars are plunged. The spectra of the nebula and of the stars exhibit the same lines. Can there be any doubt that the stars were formed from the nebula?

In passing from the white stage of infancy the star shrinks more and more. The result is a change in the spectrum. The metals calcium and iron appear in their characteristic lines. Vega and Sirius are stars of this type. As the star ages the hydrogen lines thin out and the lines of the metals become stronger and more numerous. When a stage is reached corresponding with that of our own Sun, a yellow stage, which may be considered the very summit of stellar life, some twenty thousand metallic lines appear. Then comes a gradual cooling. As it changes in hue from yellow to red, more complex chemical combinations are found in the star, and carbon makes its appearance. Then follows a stage represented by the planet Jupiter, still gaseous, still hot, but no longer markedly luminous without the aid of the Sun's borrowed light. A further step brings with it external solidification, the formation of a crust enclosing a hot interior, at which point the Earth has arrived. The last and most pathetic period is represented by the Moon—frozen, desolate, dead.

CHAPTER XXVII

NEWTON AND EINSTEIN

BY

FLOYD L. DARROW

BRIDGING the gap from the age of Galileo to the beginnings of modern science, stand the life and work of Sir Isaac Newton. Although two centuries have passed since the time of this astronomer of the British Isles, his name will in future be linked with that of the new genius of science, Albert Einstein. Men have not yet ceased to marvel at the revolutionary ideas of gravitation, space, and time that Einstein has so recently set forth. Yet Einstein only supplements Newton. He does not overthrow him. He gives us new viewpoints. He sharpens our intellects. He makes predictions which the scientists verify with startling accuracy. He explains century-old mysteries. Still, within the limits of our solar system, the laws of Newton are as valid as ever. Whether gravitation be regarded as a mere force, or a "warp in space," the consequences of a fall from the Woolworth Building or the Eiffel Tower will be just as disastrous, whichever viewpoint you take. According to Einstein's own theory, it is all a matter of "relativity" anyway, an idea which we shall make clear a little later.

NEWTON

Born in 1642, the year of Galileo's death, frail and sickly as a child, Sir Isaac Newton gave no promise of the fullness of years which were to crown his active life. Neither did his early work as a student give indication of the achievements that were to be born of his genius. As a lad, he exhibited a strong mechanical bent, but not much aptitude for study. Even at college, when he presented himself for a scholarship, he gave a poor impression of his mental ability. But the study of the geometry of Euclid aroused his interest in mathematics, and soon the intellectual world knew that a sleeping giant had been awakened.

Everyone has heard the story of Newton and the falling apple. In 1666, when only twenty-four, he was driven from London by the Great Plague. As you will recall, seated one day in the little garden of his estate at Lincolnshire, he was aroused from a deep reverie by

the falling of an apple. Newton did not, as a result of this incident, discover the force of gravity. That the earth exerts a powerful attraction for objects on and near its surface had been a matter of common experience from the remotest antiquity. It had even been suggested by the Greek philosopher, Anaxagoras, that the same force which attracts objects at the surface of the earth might also hold the heavenly bodies in their orbits. But to no one before had it occurred that this attractive force might be a property common to all matter and might extend its influence to the uttermost depths of space. Much less had anyone dreamed of being able to demonstrate that universal law. In this matchless conception we see the genius of Newton displayed to the full. Like the first sweep of Galileo's telescope across the heavens, it introduced men's minds to a hitherto unknown universe of vast extent. It broadened the earth-bound souls of men and gave to all creation a new and larger meaning.

What was this idea, destined, as it proved, to mold the scientific thinking of his own and succeeding generations? Newton, musing over his observation of the falling apple, argued that it would have fallen from a height of fifty yards, of five hundred yards, yes, from the top of the highest mountain. To how great a distance, he asked, did this force of gravity extend? Would it grow less, as the distance from the earth increased? Would it ever cease? How could he answer these questions? Was there no way of testing this matter? Could the force of gravity be made to yield up the secret of its law of action? But wait. Can it be true, he asked, that the same force which draws the apple to the earth also holds the moon in its orbit? A mighty query was this. Imagine yourself asking it for the first time in the history of the race. Then try to realize the feelings of anticipation with which you would proceed to determine the truth or falsity of this momentous question.

How did Newton determine it? He saw at once that, if his idea were true, the moon must be a falling body obeying the same laws that Galileo had discovered a generation before. Yet you may ask, "If this be so, why does not the moon fall into the earth?" Newton answered with the statement of his First Law of Motion. *Every body tends to continue in its state of rest or uniform motion in a straight line, unless acted upon by an outside force.* He considered the moon as having a motion of its own, which, should the force of gravity be released, would cause it to fly off into space in a straight line, tangent to the curve of its orbit. The gravitation of the earth, producing an accelerated motion toward its center, together with the moon's own tendency to move with uniform velocity in a straight line, would cause our nearby neighbor to follow precisely the path about us that it has and will, from its beginning to the end of time. Could this idea be true? Was here a heavenly body which constantly

falls toward the center of the earth and yet never approaches closer to it? To Newton it was clear as sunlight. Granted the conditions which he had assumed, the thing must be so. To him it was as simple as the whirling of a ball attached to a string. The constant pull of the hand on the string is the force of gravity, and any boy knows that, should the string break, the ball will fly off in a straight line.

Newton's next step was to test his theory. From the known distance of the moon and its rate of motion, Newton calculated the distance that it falls away from a straight line and toward the center of the earth in one minute of time. Although twenty years passed before his final proof, comparing this distance with that required by the law of gravity, he found that the moon is as truly a falling body as was the apple which fell in his garden. As he proceeded with the calculation, and the truth of his great discovery dawned upon him, he was overwhelmed with emotion and compelled to leave the completion of the simple computation to a friend. Well he might be. Here was the first clew to an explanation of the motions of the heavenly bodies. Out of the maze of ancient guesswork, interwoven with the discoveries of the new astronomy, he could see emerging a system of perfect law. One more step had been taken toward unraveling the eternal mysteries of the universe.

Kepler had shown the orbits of the planets to be ellipses with the sun located at one of the foci of each. He also discovered the laws governing their motions. It remained for Newton to demonstrate that these motions are the direct result of the gravitation of the sun, just as the motion of our moon obeys the gravitation of the earth. As a result of a prodigious amount of mathematical calculation, he brought under the sway of this law the rising and falling of the tides, and the motions of the satellites, comets, and meteors of our solar system. During the last century, Neptune, the outermost member of our planetary system, was discovered solely through the aid of Newton's Law of Gravitation. A more striking confirmation of the seeming truth of a great principle is to be found nowhere else in the history of science. In more recent times this law has been made to embrace the motions of the stars. For two and a half centuries it held undisputed sway, and even now, for all practical purposes, its dominion is as vast ever.

Einstein

But how has Albert Einstein, this Swiss Jew holding a professorship in the University of Berlin, changed our ideas of the universe? What is this strange doctrine which has fallen like a bomb into a peaceful camp, upsetting our orthodox notions of the eternal verities of time and space and spreading dismay among the worshipers of a

sacred past? Is this new theory a finespun fiction of the imagination or does it rest upon a solid basis of experimental fact? Abstruse, revolutionary of much that we have been taught to believe, difficult of picturing to the mind's eye, indeed, this new knowledge is. But where the path of truth lies, there must the scientist follow.

The new view of our universe divides itself into two parts. The earlier one was proclaimed in 1905 and has to do with the bewildering paradoxes of relativity. The other is an all-embracing and equally astonishing doctrine of gravitation. Just as the scientists, after three centuries of arduous labor, had placed this old world upon a bed-rock foundation of absolute security, along comes this disturber of universal peace and plunges us once more into the depths of medieval chaos. But when a man makes startling predictions and the scientists verify them almost to the letter, he must be reckoned with. Much as we should like to do so, we cannot sidetrack him.

To make this matter of relativity clear, we shall take a few familiar examples. Let us consider the idea of motion. Einstein says there is no such thing as absolute motion. That is, the motion of a body is always relative to something else. It never proceeds in a perfectly straight line with absolutely uniform velocity. A body falls to the earth, but at the same time the rotation of the earth carries it forward at the rate of a thousand miles an hour at the equator, and the revolution about the sun hurls it through space with a speed of eighteen and one-half miles a second. In addition, our whole solar system is moving toward the star Vega with a constant velocity of twelve miles a second. To us this body seems to fall in a straight line, but its path is really a long and complicated curve. Furthermore, the motions of the heavenly bodies are only relative. Were our earth enveloped in a dense mist so that we could not see the sun, moon, and stars, we should never be able to discover any motion. The heavenly bodies move with respect to each other, but there is no means of telling whether there is any absolute motion of our universe through space. If a swarm of bees were flying about inside a large, hollow sphere, there would be relative motion of the bees with respect to each other, but they could never discover whether their sphere were being carried through space. The motion is relative, not absolute. Would there be any sound, if there were no ear to receive it? Yes, and no. It is a matter of relativity. It depends upon your viewpoint. To the physicist the sound waves are there, independently of any ear to hear them. But in the physiological sense there is no sound. When we say that a room is so long, what do we mean? We mean that it is so many yards long as measured by a yardstick, which is just as long as the distance between two marks on a bronze bar at a temperature of freezing water kept in the archives of London. Measurements of every description are

relative to something else. There is nothing absolutely fixed in the universe. That is Einstein's contention.

Einstein also makes the startling assertion that time and space are purely relative. There is no such thing as empty space. There would be no space, if there were nothing to put in it. So with time. There would be no time, if nothing ever happened. Furthermore, Einstein links space and time into an indissoluble unit. Nothing could exist in space, if there were no time. Just think of it for a moment. Could a house exist in space, if there were no duration of time? Newton and all his followers down to the present day have thought of time and space as distinct and unrelated elements of the universe. But one can not exist without the other. Time is Einstein's fourth dimension. You cannot define an event without locating it in a three-dimensional space and stating its position in a fourth dimension of time. The values that we assign, too, to space and time are wholly relative. If everything in the universe were overnight increased tenfold in size, including our retinas, we could never discover that fact. Our measuring rods and our sense impressions would all correspond with the new order. How do we measure time? By the movement of a hand over a dial and the motion of the heavenly bodies. It is always relative to something else. A minute may sometimes seem an eternity and hours as fleeting seconds. It is all relative to the observer.

Einstein was led to develop his theory of Relativity from a consideration of the famous experiment made in 1886 by Michelson and Morley to determine the absolute motion of the earth through space. Because it is unthinkable that light and heat energy should travel in wave form millions of miles from the distant sun and stars to our earth without something in which to travel, scientists have filled all space and the pores of matter itself with a luminiferous ether. This ether was thought to be without weight, and resistless to the motion of the heavenly bodies through it. If the earth, then, has an absolute motion through space, why would it not be possible to measure its velocity, as this fixed ether streams through its pores? The earth revolves about the sun with a velocity of eighteen and one-half miles per second, but does it have an absolute motion through space? To answer this question, Michelson and Morley devised an experiment similar to the case of a swimmer who should attempt to determine whether it takes more time to swim a mile up-stream and back, or a mile across-stream and back. In their experiment the swimmer was a ray of light, part of which was sent a definite distance in the direction of the earth's motion and back, and the other part an equal distance and back at right angles to the former path. By an exceedingly sensitive apparatus, capable of detecting differences of one-twenty-five-millionth of an inch in the path of a ray of light,

these observers noted the instant at which both rays of light returned to the starting point.

A simple calculation will show that it takes the swimmer longer to go up-stream and back than it does across-stream and back. But imagine the amazement of Michelson and Morley to find that both rays returned at the same instant. The experiment was repeated many times and at various seasons of the year, but always with the same result. The motion of the earth, if it has any, seemed to have no effect on the velocity of light. The ether did not seem to drift through the earth, and a previous experiment by Sir Oliver Lodge had seemed to prove that it was not carried along with the earth. Here was an apparent contradiction, a blind alley from which there appeared to be no escape.

At this point Einstein came upon the scene. He put forth the two fundamental propositions, that *all motion is relative,* and that *the velocity of light is independent of the motion of its source.* Both of these had seemed to be confirmed by the Michelson-Morley experiment.

From them Einstein proceeded to draw certain sweeping and disturbing conclusions. We shall state a few of them. The velocity of light is the greatest velocity possible to obtain. A person flying with the velocity of light would never grow old. Were it possible for him to fly with a velocity greater than that of light, he would actually grow younger. A yardstick moving directly away from us and flying with this velocity of one hundred eighty-six thousand miles per second would have no apparent length, although to an observer moving beside it, the length would be as great as ever. Were it moving with a velocity of one hundred sixty-one thousand miles per second, its length would shrink to one-half. Were it possible for you to move away from the earth with the velocity of light, events on the earth would seem to stand still. Nothing would ever happen. Time would cease to exist. The hands of a clock would never move. Could you move with a velocity greater than that of light, you would overtake the light waves of previous generations, and the panorama of history would be viewed in reverse order. The mass of a body, which we have thought to be invariable, increases with its velocity, becoming infinitely great at the speed of light. Because of these facts, our judgments of motion, time, and distance are relative to the observer. The events of our earth to an observer on an airplane moving by us with half the velocity of light would have very different values from those which they have for us.

But let us remember that at no velocities possible to obtain on this planet will the measurements of time, space, and matter vary in the slightest degree from what they appear to be under the older physics of Newton and his successors. The differences exist, but to detect

them would require measuring instruments a million times more accurate than any which it is possible to make.

But what of Einstein's new view of gravitation? It will be to his everlasting credit that for the first time in the history of men he considered the possibility of another explanation of why bodies fall to the earth than that of Newton. Why assume a mysterious force of gravitation? Is there no other way of accounting for the apple's fall? Einstein said yes.

Suppose you are sitting in a motionless room in empty space, millions of miles from any attracting body. You will have no weight. Your hat will not press down upon your head. Your body will exert no pressure upon the seat beneath you. A ball released from you hand will not fall. A spring balanced will register no weight. Then suppose that the room begins to rise with an accelerated velocity exactly equal to that of a falling body at the surface of the earth. Immediately you will have weight and exert pressure upon the floor. The ball will fall. The spring balance will measure the weight of any body to which it is attached. The effects which you observe will be precisely those of gravitation. But you will be unable to discover by any possible means whether it is some mysterious force of gravity that is producing these effects, or the accelerated motion of the room in which you are seated. So with the earth and our solar system.

In his revolutionary ideas of gravitation, Einstein starts with the proposition that wherever there is matter, space is curved. This seems absurd. How can space be curved? Is it not possible to draw straight lines in space? Does the straight-line, three-dimensional geometry of Euclid no longer hold in our universe? But did you ever observe the objects of a room as reflected in a slightly concave mirror? In it the straight-line space of our room has been warped and distorted. Just so, Einstein considers that the four-dimensional time-space of our universe is warped in the vicinity of a great mass of matter like a planet or our sun. How this may be, it is difficult to picture to the imagination. Our nearest approach to it is to think of intelligent two-dimensional beings placed upon a sphere. They have no knowledge of a third dimension. They regard the surface of their universe as flat. Parallel lines will never meet and no straight line will ever return to its starting point. The introduction of a third dimension will be as upsetting to their fixed notions of space as is Einstein's curved space view to our ideas. But just as these two-dimensional beings would have false ideas of their world, so may we be wrong and Einstein right.

What has all this to do with gravitation? Just this: that a planet may follow an elliptical path about the sun and an apple fall to the ground, not because of any mysterious force of gravitation, but be-

cause these paths are the lines of least resistance through a space that has been warped and curved by the presence of a large mass of matter. If we should find that a marble placed at any point near the walls of an apparently level floor always rolled to the center of the room, either one of two possible explanations might be given. There is some force attracting the marble, or the floor is curved. So with gravitation. Either there is some force of attraction common to all matter, or space is curved. Newton took the former view. Einstein has chosen the latter.

Is there no way of testing this matter? Yes. Einstein says, if my view is correct, if space is curved, then a ray of light from a distant star in passing by the sun ought to be bent out of its straight line path. On May 29th, 1919, two British expeditions, one to Brazil and the other to the west coast of Africa, took photographs of the sun and the stars at the time of a total eclipse. These photographs were compared with others taken several months later, when the sun was not in that portion of the heavens. As a result, it was determined beyond the possibility of doubt that the starlight had been shifted, and shifted very nearly the number of seconds of arc the Einstein had predicted it would be. Here was an astronomical triumph of the first magnitude. It has been surpassed by no other and equaled only by the discovery of Neptune. Preliminary reports of more recent observations have also confirmed Einstein's view.

Yet this was not all. From his theory that the mass of a body increases with its velocity, Einstein gave a perfect explanation of a hitherto unaccountable discrepancy in the orbit of Mercury, which had puzzled astronomers for generations.

Were it not for these two remarkable experimental proofs of this new theory, we should long since have consigned Einstein and his revolutionary ideas to the realms of pure speculation. But when a scientist's theories square with the observed facts of nature, the world cannot ignore him. In the centuries to come it will be to the glory of this physicist from across the seas that he has taken us a long way nearer to an understanding of the ages-old mysteries of time and space. To the end of time the names of Newton and Einstein will stand as symbols of two of the mightiest intellectual achievements of the race.

CHAPTER XXVIII

ATOMS, MOLECULES, AND ELECTRONS

FLOYD L. DARROW

ATOMS, molecules, and electrons—what are the meanings of these mystic words? Are they but fictions of the mind, the artificial symbols of an imaginary realm? What counterpart, if any, do they have in reality? What relation do they bear to this humdrum, matter-of-fact world? Why trouble ourselves with thoughts of entities so infinitesimally small as to be almost inconceivable? And the answer is, because they are the raw materials from which this universe has sprung and into which it may revert. They are the magic keys which unlock for us the ante-room to the eternal mysteries of energy and matter. They reveal the secrets of the ages. They disclose the "philosopher's stone" and bring the dream of the alchemist to pass. They usher us into a new world, as vast and awe-inspiring as the infinite depths of space. They are the threads in the loom on which the Master Artist weaves his magic tapestries. They paint the gorgeous colors of the rainbow and the sunset. They flood the heavens with the delicate glow of the beautiful Aurora Borealis and explain away the wonder of the zodiacal light. Their majestic sway extends from the tiniest speck of matter to the remotest bounds of the universe. Walls may crumble and empires fall, civilizations drop from off Time's bough, worlds come and go, this universe resolve itself into primeval chaos, and still atoms, molecules, and electrons will remain, the primal stuff from which creation will proceed anew.

Still what are atoms, molecules, and electrons? They are the building blocks of the Great Architect. They comprise all matter, including ourselves. They are the sources of every form of energy. All space swarms with electrons. These infinitely small bits of raw materials are the working capital of the universe. A swarm of atoms, molecules, and electrons in the shape of lead meets another swarm in the shape of an individual, and a human tragedy is wrought. An aggregation of these cosmic units, masquerading in the guise of meteoric matter precipitates a whirlpool at some point of space, and a world begins to evolve. A stream of electrons moves along a copper wire, and we have an electric current. The lightning flashes, and countless trillions of these sub-atomic fireflies zigzag from cloud to cloud or mayhap to the earth. We might multiply examples, but let us turn back to the beginning.

First Ideas of Atoms

The first conception of atoms came from the Greeks more than two thousand years ago, but it was only a happy guess. The scientists of this imaginative race did not experiment. The laboratory was unknown to them. They dealt only in speculation. Still it seemed reasonable to suppose that matter is not infinitely divisible. There must be some stopping point. And so, Democritus invented a theory of atoms surprisingly similar to the modern view. To this brilliant Greek the universe had evolved from a happy gathering together of these bricks of cosmic matter. And there he left the subject.

Of course people probably spoke of "smashing things to atoms," but no one bothered himself seriously about the existence of such exceedingly doubtful points of matter until the time of John Dalton more than a century ago. This English schoolmaster and famous chemist put forth a theory of atoms which has held sway until the present day. But this pioneer of a new era in scientific thought based his ideas upon experimental evidence. And as the bright morning of chemical discovery passed toward the noonday of its triumphs, the proof of his theory was piled mountain high. He stated his idea thus: "Elements are made up of smallest particles called atoms, and chemical compounds of the elements are formed by the union of these atoms in simple numerical proportions."

I say that Dalton's belief has been proved. It has been, and more. There is no lingering doubt as to the existence of atoms. But they are not the smallest particles of matter, as we shall see, an atom is a miniature solar system, giant in size compared with the electrons that revolve about its center. And even yet, where the path of investigation will lead, whether we have reached the ultimate reality, no man can say.

Elements and Compounds

A moment ago I mentioned elements and compounds, and now I must define them. Of the elements, you are all familiar with many of them—lead, iron, copper, tin, nickel, silver, and quite likely gold. For a century and more an element has been a substance which can not be changed into anything different from itself by any known means. We say *by any known means,* for many a supposed element has been resolved into atoms of different kinds. But, as I shall show you, in the light of modern discoveries this definition seems to be breaking down. Of one thing we are sure. This universe consists of ninety-two elements and no more. There are just ninety-two kinds of atoms, and we have found eighty-seven of them. Only five more remain to be discovered. And now the scientists have found that these elements consist of one common, primal stuff. They are simply aggregations in varying number of negative electrons revolving about centers of posi-

tively charged nuclei. Just think of it, a grand unity pervades the universe. The clay beneath your feet, you yourself and all that you may see, are kin to the dog star, the fire mist of the Milky Way, and every other particle of matter in the universe. And how do we know all this? We shall see.

But what of molecules and compounds? If by chemical means I break down common salt, known to the chemist as sodium chloride, I shall obtain an exceedingly caustic, metallic substance called sodium and a poisonous, greenish colored gas named chlorine. As yet, no chemist has been able to resolve sodium and chlorine into anything simpler than themselves. They are elements, each made up of countless myriads of atoms, and every atom a minature solar system of simpler units.

I pass an electric current through pure water and behold two gases, hydrogen and oxygen, collect in my apparatus. A seeming miracle has been wrought. Water, the chief agent in the fighting of fire, has been decomposed into two gases, one of which is the world's principal supporter of fire, and the other, one of the most combustible substances known to science.

Evidently in the physical division of sodium chloride there comes a point where the salt ceases to be salt and becomes elements of sodium and chlorine. The smallest particle that can exist and still have the properties of salt is a *molecule*. When we get a still finer division, atoms of the constituent elements appear. And likewise with the water. The tiniest particle that can exist and still be water, is a molecule. The droplet that paints the rainbow, and the infinite volume that makes the vastness of the sea, are both composed of innumerable trillions of these inconceivably small molecules of hydrogen and oxygen.

And now you know what a compound is. Ordinary salt is a compound, and so is water.

What a mad phantasmagoric dance these atoms and molecules lead! In the various combinations which are possible to them, we may have two-hundred-and-fifty thousand different kinds of molecules. Vibrating, combining, dissolving—they may lie in the soil today or flit through the atmosphere, and tomorrow blossom in the rose. Every living creature and every inanimate object are but aggregations of these universal units.

More About Atoms and Molecules

We speak of atoms and molecules as though they were as common as cobblestones, and yet no human eye ever saw an atom or a molecule, and never will. They are utterly beyond the reach of the most powerful microscope, and we have reached the limit of magnification in the construction of this instrument. True, the ultramicroscope does enable us

almost to catch a glimpse of some of the largest molecules, such as those in a grain of starch, but the miracle of actual seeing them can probably never be accomplished.

Can we get an idea of the sizes of these molecules and atomic units? Let us see. The diameter of an atom is a million times smaller than the thickness of a hair. A cubic inch of any gas will contain four-hundred-and-forty one quintillion molecules and still leave "oceans" of space for billions and billions more to be packed between them. If the temperature about our planet should suddenly cool to two hundred degrees below zero on the Centigrade scale, the atmosphere would form an ocean of liquid air only thirty-five feet deep. When we consider that the atmosphere extends outward for a distance of possibly fifty miles, we see what vast reaches of space must lie between its molecules, for even in liquid air the molecules do not touch. At still lower temperatures, the molecules come somewhat closer together and we have a solid.

Matter is porous, and the spaces between the molecules are infinitely larger than the molecules themselves. Sugar dissolves in water, which simply means that the molecules of the solid find their way with perfect ease between the huge spaces which separate the molecules of water. Even solid gold forms a perfect solution in liquid mercury If we could look within the densest solid, we should see billions and billions of these infinitesimal particles moving with great velocities in hit-and-miss fashion, colliding, rebounding, jostling, forever engaging in a mystic dance of perpetual motion.

But how large is a molecule? We may beat a piece of gold into a leaf, nearly one four-hundred-thousandth of an inch in thickness, infinitely thinner than the thinnest paper. And still the gold leaf would contain many layers of molecules. We may blow a soap bubble to a thickness of one three-millionth of an inch, and still the scientist estimates that even here the molecules must lie tier on tier twenty or thirty deep. Again, a film of oil on the surface of water spreads out to the inconceivable thinness of a fifty-millionth of an inch, but the scientist tells us that we still have a double layer of molecules. And when we remember that the thickness of this film comprises the diameters of two molecules together with the much larger space between them, we see how past all comprehension is the smallness of a molecule.

A tiny bubble of chlorine gas will scent a large room. The trillions of molecules which it pours forth must make their way to the remotest corners of the room. A single grain of indigo will distinctly dye a ton of water. And a grain of musk will scent a room for years. To contemplate the prodigious numbers of molecules required to make these phenomena possible bewilders thought and staggers the imagination.

Professor Millikan tells us that the molecular population of a cubic centimeter of air is twenty-seven billions of billions, and a cubic centimeter is less than a small thimbleful.

Atoms and Electrons

But, if it appears that molecules are small, what shall we say when we consider atoms and electrons? Although atoms vary in size and weight, it would require on an average four hundred million of them side by side to make an inch. A quintillion atoms of gold would be needed to weigh fifteen grains. Sir Oliver Lodge estimates that an atom of hydrogen weighs twenty-five ten-thousandths of a grain divided by *one* followed by twenty-one zeros. Or, putting it in another way, an atom of hydrogen weighs a million million million times less than a grain of lycopodium powder.

Let us take a peep within the atom itself. In order to get a better view, we will magnify the earth and all it contains ten billion times in size. On this scale an average atom will be about three feet in diameter. And what do we see? Surely not the hard, smooth, shining sphere which the ancients fancied, but figuratively speaking a vast solar system with a central sun, and planets revolving about it at almost inconceivable velocities. We look again and to our amazement find that the atom seems almost infinitely porous. How could we ever have thought it solid? Between the planets, called electrons, and the central nuceleus, and between the electrons themselves, are vast dreary wastes of space actually greater in comparison than the spaces between the members of our own solar system. And I am not dealing in fictions of a disordered brain. These statements are proven facts, as true as that two and two make four.

We quickly examine the atomic systems of different elements and find that they are all alike. In every one there is the central nucleus and the revolving electrons, but the number of electrons vary with the different atoms. An atom of hydrogen has a single electron, helium two lithium three and so on up until we come to uranium, the heaviest and last of the elements, which has ninety-two. These electrons revolve in their orbits with varying speeds, but according to Rutherford, an eminent British physicist who has done more work in this field than anyone else, the velocity frequently reaches ninety-three thousand miles per second, half that of light. What dreamer could have imagined it a generation ago—molecules inconceivably small and made up of atoms infinitely smaller, which consist of electronic systems, as majestic in their reign of perfect law as the stupendous systems of the starry heavens?

One fact about this atomic system compels attention. The nucleus, instead of being large like our sun, is infinitesimally small. Even

when magnified ten billion times, it is no larger than the point of a pin. Millikan states it is about one-billionth as large as the smallest object that can be seen with the aid of the most powerful microscope. And yet, amazing as it may seem, it comprises practically all of the mass of the atom.

And, now that we have analyzed the atom and delved into it to its inmost center, have we reached the limit? Are there still other discoveries to be made in the constitution of matter? Will the electrons and nuclei themselves be still further resolved? Well, we shall see. There is still light to be shed upon these questions.

Along the Pathway of Discovery

Let us go back a century and follow the star of destiny as it leads us from one discovery to another. After Dalton had put forth his theory of the atoms, experimenters in every laboratory of Europe began to push back the frontiers of chemical knowledge. Berzelius, the great Swedish chemist and the czar of chemistry for half a century, showed that these atoms really do exist and that it is possible to determine with the utmost accuracy their relative weights. By relative weights, I mean the weights in which the elements actually enter into chemical combination. For instance the atomic weight of hydrogen is one and of oxygen sixteen. Two atoms of hydrogen combine with one atom of oxygen to form a molecule of water. This means that by actual weight two grams of hydrogen unite with sixteen grams of oxygen to form eighteen grams of water. I have heard Professor Richards of Harvard say that these atomic numbers are the most significant set of physical constants in the universe, that, if all matter should be resolved into primeval chaos, still the atoms would recombine to form new compounds in strict numerical proportion to these numbers.

And so the atom became what it is today, the practical working unit of the chemist.

The Spectroscope and its Revelations

Just past the middle of the last century Vunsen and Kirchhoff, two distinguished German chemists, came forward with the spectroscope, one of the most marvelous instruments ever designed by the brain and hand of man. With it the constitution of matter both in the laboratory and in the most distant stars stands forth as an open book. The vibrations of these tiny electronic systems when heated to incandescence send out ether waves which reveal their inmost secrets.

The light from any incandescent solid, liquid, or gas is focused upon a glass prism, which disperses it into its component colors and

passes it into a small observation telescope where these tell-tale colors are magnified into a broad band or a series of bright lines. The light from an element in the state of incandescent vapor gives a series of bright lines which are characteristic of that element, that is, they are different from those of any other element. If the light comes from a solid, a liquid, or a gas under a great pressure, a band of solid color appears. If from a gas under small pressure or a vapor, a bright-line spectrum with dark spaces between results. With this wonderful instrument we are able to know just what elements are present in the sun, the distant stars, the nebulæ, and the comets. We may also tell their physical constitution and whether these bodies are moving toward us or away. So delicate is it that as minute a quantity as one two-hundred-thousandth of a grain of sodium may be detected with perfect ease and certainty.

But why have I described the spectroscope in connection with atoms, molecules, and electrons? Because it shows us that there is a wonderful significance involved in the structures of the different atoms of the elements. Why should the vapor of mercury give a spectrum of more than two hundred bright lines of various colors and sodium only two? Until the discovery of electrons and their solar systems this was all a mystery. But now we know that the electronic system that spells mercury in the eternal scheme of things is a different aggregation of units from that which constitutes sodium. Something fundamentally different in the vibrations and planetary movements of these two systems produces distinct and characteristic sets of colors.

And once more out of the darkness of the unknown comes the searchlight of truth.

The Periodic Law

A little more than a half century ago, the Russian chemist Mendelèeff and the German Lothar Meyer independently discovered a wonderful system lying back of the seeming chaos of atomic properties. Arranging the elements in the order of their atomic weights, it was found that every eighth element repeated the properties of the eighth element preceding it. Surely this looked like the coming of the reign of law and order. Possibly the veil was to be drawn aside and the hidden mysteries of the atoms and the molecules revealed. As Robert Kennedy Duncan has beautifully expressed the law: "Just as the pendulum returns again in its swing, just as the moon returns in its orbit, just as the advancing year ever brings the rose of spring, so do the properties of the elements periodically recur as the weights of the atoms rise."

True this law led to the correlation of chemical knowledge and many new discoveries, but it was not until we were acquainted with

atomic systems of electrons that its real significance became apparent. The atomic structures of the elements now show clearly why certain elements are brothers, sisters, and cousins.

Radioactivity

Toward the close of the last century came one of those great tidal waves of scientific discovery which forever stands forth as a boundary-line between one epoch and another.

In 1879, Sir William Crookes discovered that, when a discharge from an induction coil or a source of high voltage electricity is sent through a vacuum tube, a peculiar set of rays is given off from the negative pole. He called them "cathode rays." Within a short time it was shown by Sir J. J. Thomson and others that these rays consist of minute negative particles which are attracted by the positive pole of a magnet. By experiment it was found that of whatever substance the negative electrode, or cathode, might consist these negatively charged particles invariably formed. Could it be possible that at least they had found the primal stuff of all creation? Indeed, it seemed. Let us see.

Thomson investigated these particles and showed that they consist of nothing but pure negative electricity, for a moving electric charge may have the properties of mass and inertia, the fundamental characteristics of matter. Had the hard-and-fast substances of the material world at last been resolved into mere points of energy? Again, so it seemed. Thomson named these new members of the material universe *electrons.* His researches proved that an electron is about one eighteen-hundredth as heavy as an atom of hydrogen, the lightest of the elements. His work had brought him to the very gate-way of the atomic mysteries.

As you all know, shortly after, in 1895 to be exact, Röentgen discovered the x-ray. He found that wherever these electrons, moving with a velocity approaching that of light, strike upon the opposite walls of the vacuum tube or upon a screen placed in their path a wonderul new light appears. With these x-rays and their marvelous penetrating power, we are all now familiar. But mark you these rays represent the energy set free when swarms of moving electrons come to grief within a vacuum tube. We might note in passing that the number of vibrations necessary to produce these waves is three quintillion per second.

What Next?

I cannot repeat here the story of the Curies and their discovery of the marvelous element *radium.* We must be content with pointing

out its immense significance to our understanding of the true nature of atoms and electrons.

As a result of one of the most Herculean tasks in the history of chemical research these now world-famous investigators obtained a few milligrams of an element more wonderful than any that had ever before been discovered. In the light of its astonishing properties the subatomic world has been made to yield up its secrets. And it points the way to a source of power which may mark the supreme achievement of the race.

Here was not merely the discovery of a new element, but the key to a hitherto undreamed of realm of the most interesting and illuminating chemical phenomena. Here was atomic disintegration. Radium spontaneously and without ceasing gave off three kinds of rays. They are called *alpha, beta,* and *gamma.* The alpha rays turned out to be positively charged atoms of *helium* moving with a velocity of about twenty thousand miles a second. The beta rays were identical with the electrons of the Crookes' tube, projected in a constant stream at velocities of from sixty thousand to one-hundred-eighty thousand miles per second. And the gamma rays proved to be x-rays just as we would expect in the presence of swarms of swiftly moving electrons. And with it all was the liberation of a vast quantity of energy in the form of heat and chemical effects.

But let us see what this means. We have not even yet reached the end. In this breaking up of the radium atom our old definitions of atoms and elements were sadly mutilated. For here was a substance, answering in every other way to the definition of an element, but which spontaneously decomposed into the element helium and a whole series of transitory elements ending in the final product of *radio* lead.

Had not the ancient dream of the alchemist come true? Did we not stand in the presence of natural alchemy. But it was a process which man could neither speed nor stay. We may stand on the sidelines and watch its progress, but we are powerless to influence it in the slightest degree. Still it was a magnificent revelation, and some day we may discover the key to its control.

But scientists asked "Did we have an eternal fount of energy?" Had something akin to perpetual motion been discovered? Soon the answer came. The life story of radium was found to be seventeen-hundred-and-thirty years. This, as scientists interpret it, means that in this period half of any given quantity of the element will disintegrate, in another equal cycle half of the remainder and so on. It also became apparent that radium is continually being formed in the earth's crust from some other element, and that element has been found to be uranium. Its atoms disintegrate yielding in the end radium. And its life history has been computed to be *eight billions*

of years. Think of what this means: This earth, instead of being a niggardly hundred millions of years old, undoubtedly has an age extending into the billions of years. The geologist and biologist may now have almost infinite periods of time for the working out of their natural processes.

Subatomic Energy

But the most interesting fact of radium is the practically inexhaustible supplies of energy which pour forth from the disintegration of the electronic systems of its atoms. It has shed a flood of light upon ages-old questions and points the way to splendid future conquests.

A problem that has perplexed scientists for centuries is the source of the sun's heat. No adequate explanation could be given. And then the spectroscope revealed in the atmosphere of the sun prodigious quantities of helium. With the discovery of radium the mystery seemed solved. We have seen that one of the disintegration products of radium is this very element helium. Is it not possible, and even more than probable, that the sun contains vast quantities of radium, which on disintegrating maintains the heat of our solar center? At present science has no better answer.

The energy yielded by the ceaseless rain of radium electrons is enormous. Sir Oliver Lodge has estimated that so small an amount as one-seventieth of a grain of radium hurls into space thirty million electrons per second. In the complete disintegration of a gram of radium, scientists estimate that two billion nine hundred million calories of heat will be evolved, or more than a million times more than that obtained from the combustion of a gram of coal, the chief fuel of the present age.

But this is not all. The atoms of all the other elements are infinite reservoirs of energy. Again Sir Oliver Lodge has stated that the energy locked up within the atoms of an ounce of water would be sufficient to lift the German fleet sunk at Scapa Flow and place it high and dry on the mainland. Professor Le Bon of Paris states that the energy possessed by the smallest French coin is equal to eighty million horsepower. Robert Kennedy Duncan asserted that the power within the atoms of a single breath would run the workshops of the world.

Shall we ever be able to tap these inexhaustible founts of energy? Time alone can say. But of one thing we may be perfectly sure: What the race earnestly longs for, it will achieve. When the present sources of power are exhausted, there must be some other supply. Is it not more than likely that the energy within the electronic systems of the atoms will meet the world's need?

All substances at a high temperature emit electrons. The sun is a

prodigious source of them. Our earth and all else within its range is being ceaselessly bombarded with them. And this fact explains some ancient mysteries. These electrons coming with their enormous velocities into the highly rarefied upper layers of our atmosphere produce the soft radiance of the Crookes' tube, and we have the beautiful Aurora Borealis. The faint, soft beams seen on the western horizon just after twilight of a winter's evening and known as the zodiacal light are undoubtedly due to streams of electrons as they come into our atmosphere and pass by the earth on either side. The bombardment of meteoric matter in space may produce the light of the nebulæ, those vast whirlpools of cosmic action which we regard as other worlds in the process of formation. We suspect that the spots on the sun are huge electric cyclones. It is even thought that the varying physical conditions of the stars, as revealed by the spectroscope, are due to the effects of temperature upon the atoms, electrons, and molecules of these distant sun's. The mystery of an electric current resolves itself into a stream of electrons moving along a conductor. And a magnetic field is the strain in the ether set up at right angles to it.

Today the wonderful achievements of the radio art are made possible by streams of electrons within a vacuum tube. And tomorrow these never-tiring servants of the race may bring to pass the miracle of the wireless transmission of electric power. What the future may hold no man can say. But there is no shadow of doubt that we stand at the dawn of a new day.

Yes, molecules consisting of atoms, and every atom a solar system made up of nothing whatever but a central nucleus of positive electricity with electrons of negative electricity revolving about it—these seem to be the ultimate realities of science, the primal stuff from which all creation will forever spring anew.

ANTHROPOLOGY

INTRODUCTION

No OTHER science deals with a field so ill defined as Anthropology, no other studies so varied and differing material. The scope and the content of the science are alike matters of dispute. By derivation the word of course means a discourse or treatise regarding man. It has been defined as that branch of science which studies man in the same way as geology investigates the earth or as botany investigates plant life. The motto of the Department of Anthropology in the World's Columbian Exposition was "Man and his works." It is evident that any science which studies man and his works has a limitless field. Anthropology depends upon the whole range of other sciences. It has a dozen connections with Astronomy; it is closely related with Geology; it assumes an enormous knowledge of Biology; to a great degree it includes Anatomy, Physiology, Psychology; it uses the methods of Mathematics; it is intertwined with History; Linguistics and Philology yield a notable contribution to its store. Is it possible to mark out a definite field for its investigation and to group and classify its materials? More and more its students feel that it has its definite field, its legitimate subdivisions and its special methods of investigation. Roughly we may divide the materials of Anthropology under the four subdivisions of Somatology, Ethnology, Ethnography and Culture History. Under the latter we must rank Prehistoric Archeology, perhaps the most popular subdivision of the field.

Somatology, or Physical Anthropology, deals with man as a living being. In reality it treats of two quite different matters: First, it investigates man's place in nature; it locates him in his proper place in the scale of animal life; it considers the question of his origin; it discusses his relation to the anthropoids and other simian forms; it aims to trace his family-tree back to a primal trunk. Second, it considers man in himself as an organism. It necessarily includes the fundamental facts of anatomy, physiology and psychology. It lays the foundation for Ethnology. Ethnology is the philosophical study of human races. If we recognize—and the distinction is a good one—the difference between "logy" and "graphy" sciences, we shall clearly understand its scope. From the materials supplied by Somatology it aims to define the types of man. Such types are based primarily upon physical characters. Color, character of hair, head-form, stature, the form and character of facial features, variations in proportion—these

and other characters are studied and combinations of them found existing among groups of human beings are built up into race types. Having defined the different types of man now existing, the ethnologist deals with such questions as the cause and extent of variation and the history of these types through the past. He is interested in the great problems of migration, acclimation, miscegenation and the like. Ethnography, as its name indicates, is a descriptive science. It bears the same relation to Ethnology that Geography bears to Geology. It is the least philosophical, the least important, but the most popularly interesting of the sub-fields of Anthropology. A general ethnography would be a complete description of the life and habits, thoughts and condition of each and every population on the globe. The special ethnography of any people is the detailed description of its entire life. Culture History deals with the same materials as Ethnography, but in a different manner. From the data furnished by the ethnographer, dissociated from the peoples, it aims to trace the progress of culture from the rudest savagery to the highest civilization; it aims to follow the evolution of ideas; it studies the beginnings and development of institutions; it is the highest product of anthropological study.

Such is the field of Anthropology, such are its most generally recognized divisions. The tendency of students is to devote themelves to one or another of these four great subdivisions. Thus practical workers are likely to be Somatologists, Ethnologists, Ethnographers, students of Culture History, Archeologists. While this is true, the propriety of a general term which shall include them all is more and more emphatically recognized.

The fact that man is himself the subject of study has made the progress of the science exceptionally difficult. Prejudice has entered into the discussion of the great problems of the science as it has not done in such subjects as Astronomy and Mathematics, Geology and Zoology. This is well shown in the great question of the unity of mankind. The battle between the monogenist and the polygenist has been a bitter one; views have fluctuated; religious and political ideas and theories have tinged discussion. Monogenism was good religion in the early part of the nineteenth century. With the promulgation of Darwinism many theologians were thrown into the camp of the polygenists as their only escape from the hated revolutionary doctrine. A whole school of American polygenists came into existence at the time of heated discussion regarding slavery. To-day the long-mooted question has little significance. Since natural selection has been established and is assumed as a working hypothesis in all the biological sciences, the question whether man is originally of one or of several species is simply the question of how far back we will draw the line across the divergent branches of the human kind.

The question of man's antiquity has been the cause of many a battle. A quarter of a century of heated discussion was necessary before the claim of Boucher de Perthes that man existed before present geological conditions was accepted. In 1859 man's antiquity was admitted as far back as the glacial period. When De Mortillet wrote his masterly manual of Prehistoric Archeology claims of greater antiquity were before the public. In one and another locality objects had been found which were believed to demonstrate man's existence in the Tertiary. De Mortillet examined the whole material. Rejecting far the greater part, he believed that enough remained to warrant the assumption that an intelligent being, a tool-user, existed in that geological division of time. When he presented his views, few were ready to accept them. To-day the whole matter has been revived and one of the most bitter discussions of the moment is being waged over the so-called "Eoliths." The crude tools for which Boucher de Perthes contended are finely finished works of art compared with the rude flakes over which the present argument is being conducted. The paleolithic relics are intentionally shaped; the eolith is simply a natural flake or splinter which shows evidence of use. The representative of the eolith argument to-day is Professor Rutot, of Belgium. His claim is distinctly that an eolith is a flake or splinter of flint, produced by natural causes, which has been used by an intelligent being for pounding, scraping, rasping, cutting or sawing. Such objects have now been found by thousands in France and Belgium, Germany and England. In age they range from the early Quaternary (or Glacial Period) back to the middle Tertiary. Against a storm of opposition and argument Rutot presents a masterly argument in favor of their authenticity. Whether these eoliths are to be attributed to man or to some other intelligent being awaits the fortunate find of remains as yet undiscovered.

It is a common assumption that primitive man was unsophisticated, a being endowed with possibilities, a creature of undeveloped talents. This assumption has been almost universal in all studies of culture history. A little thought clearly demonstrates that such a being never can have existed. Assuming man's animal ancestry, we are driven to believe that many things which are ordinarily considered as being human must have arisen in a prehuman, brute condition. It is certain that the ancestor of man must have been a social species. Is it not quite as certain that before he had developed into anything which could be considered human certain fundamental facts of social life must have existed? The simplest ideas of rights and duties, of personal property, of friendship and hostility, of the use of nature-supplied implements, of communication, perhaps of animism—raw stuff of religion—may well have been developed by the brute, non-

human ancestor. In other words, the being whom we call primitive man had already a respectable capital. This point of view renders all serious study of animal psychology particularly interesting to the anthropologist. Such books as Groos' "Play of Animals" and "Play of Men" are most suggestive. There is as yet practically nothing that can be called a study of the psychology of anthropoid apes. Such a study would be of interest and significance. Not that it is assumed that any one of the existing anthropoids is ancestral to humanity. They are our cousins, not our progenitors. A correct picture of their mental operations would not be that of our precurser, but they and we have inherited from the same ancestry.

Ethnographers to-day divide into hostile camps upon the question of the significance of similarities in culture in widely separated areas. When one finds a striking detail or feature of custom or belief in populations widely separated, the immediate and natural assumption has always been that this similarity indicated relationship or contact in the past. The assumption is a dangerous one and has been so frequently and rashly made as to bring contempt upon the method. It is so easy in finding a few simple customs among the American Indians which resemble the practices of the old Jews to assume that the Indians are the "Ten Lost Tribes of Israel"! A revolt upon the part of thoughtful students against such loose and careless comparison and assumption was natural. There is no question that this revolt has been carried to a ridiculous extreme. It finds its fullest development in Daniel G. Brinton, through years the leader in American Ethnology. For Dr. Brinton and the great school of Ethnologists of which he was spokesman, similarities in culture do not necessarily show relationship, or contact, or evidence of migration, but simply demonstrate the psychical unity of mankind. His thesis was that everywhere the human mind subjected to similar conditions would strike out similar results. The same thought, the same belief, the same practice, the same art and industry might originate independently in two or many different sections of the globe. The argument is interesting and valuable, but may become misleading. Everyone admits the psychic uniformity of man. But, for most students, close and peculiar similarities of the details in stories, in games, in religious practices, in complicated mechanical devices suggest actual contact in the past. No such contact should be carelessly assumed, every case should be rigidly investigated; but the true ethnographer must weigh with care all such likenesses.

Major Powell divided the field of Culture History into five divisions. These he called Esthetology, Technology, Sociology, Philology and Sophiology. Art, Industry, Society, Language and Belief are the five expressions of the human mind. Each is ample to fully

occupy many students for an indefinite period in the future. Each will yield its harvest. Into each the student must carry the methods of rigid scientific study. When one realizes the enormous scope of any of these and then appreciates its proper place as a small section in Culture History, itself but one of the four great subdivisions of Anthropology, he begins to realize the magnitude of the scope and content of this important study.

FREDRICK STARR.

ANTHROPOLOGY

CHAPTER I

MAN'S PLACE IN NATURE

Despite what philosophers may say, Man to himself will always be the center of the universe. It may be possible that beings superior to Man even now do exist, tho unrecognized by human sense, in the same manner that Man cannot be understood by the minute corpuscles in his blood. But such a thought is so strange to the common viewpoint that it seems almost fantastic, and Man's Place in Nature, he firmly believes, is at the top, while the only idea which has reconciled him to his manifest ancestry in the lower orders of life is that the scale of evolution points to him as the highest form yet attained.

Wherefore Anthropology, including as it does the entire past of Man, can scarcely be regarded as a single science, and the anthropologist is conscious of a certain vagueness as to the scope of his labors. Since Man in a sense sums up all that has gone before, all is included in him, and since his present position cannot rightly be understood without reference to that which has gone before, it becomes evident that a large group of arts and sciences which appear mutually diverse find an interdependence in him. The old saying, "I am a Man, and therefore nothing human is foreign to me," fairly expresses the ground upon which the anthropological sciences claim attention.

The links of Anthropology to other sciences are numerous and close. Thus there is what in France is called pure anthropology or anthropology proper, but which is better called physical anthropology —the science of the physical characters of man, including anthropometry and craniology, and mainly based upon anatomy and physiology. There is comparative anthropology, which deals with the zoological position of mankind. There is prehistoric archeology, which covers a wide range of inquiry into man's early works, and has to seek the aid of the geologist and the metallurgist. There is pyschology, which comprehends the whole operations of his mental faculties. There is linguistics, which traces the history of human

language. There is folk-lore, which investigates man's traditions, customs and beliefs. There are ethnography, which describes the race of mankind, and ethnology, which differentiates between them, both closely connected with geographical science. There is sociology, which applies the learning accumulated in all the other branches of anthropology to man's relation to his fellows and requires the co-operation of the statistician and the economist; and each and every one of these is an immense subject, while nothing has been said of the manner in which all human æstheticism traces its spring to prehistoric times.

Also there is another side to the question. Great as is the diversity of the anthropological sciences, their unity is still more remarkable. The student of man must study the whole man. No true knowledge of any human group, any more than of a human individual, is obtained by observation of physical characters alone. Modes of thought, language, arts and history must also be investigated. This simultaneous investigation involves in each case the same logical methods and processes. It will in general be attended with the same results. If it be true that the order of the universe is expressed in continuity and not in cataclysm, the same slow but sure progress must be evident in each branch of the inquiry. Thus nothing is lost, no race is absolutely destroyed, everything that has been still exists in a modified form and contributes some of its elements to that which is.

There is yet a deeper sense of study which traces back the very roots of thought, for it would be as idle to study the human body alone without reference to that of any other creature and attempt in that way to decipher its genesis, development and meaning as to attempt to comprehend a single human mind without including in the examination but equally all other minds to which that of Man is related.

The debt is never to be forgotten that is owed to all minds other than human, "belonging," as Sir Daniel Wilson once said before the American Association for the Advancement of Science, "belonging to our kinsfolk, the animals, minds which stand to-day like mileposts along the almost infinite length of the path which our mind has followed in its upward march across the immensities and eternities from its remote infancy to the present hour; minds which in a thousand faculties represent to us everywhere, in infinite sameness and variety, replicas of our own or of parts of our own, showing us, as the poet says, tokens of ourselves which we 'negligently dropped as we passed that way huge times ago.' "

"As man's bodily life rests upon and grows from that of countless prehuman ancestors," says Dr. R. M. Bucks, "as man includes in his structure the heart of the reptile, the gills of the fish, as well as the forms in outline of innumerable still lower races, so is his so-

called human mind rooted in the senses and instincts of all his ancestral species; and not only so, that these senses and instincts still live in him, making up, indeed, far the larger part of this current everyday life; while his higher psychical life is merely the outgrowth and flower of them.

"As truly as the plant is an embodiment of inorganic matter vivified by the transmuted forces which in the nonvital world about us we call light and heat, so truly is man's mind the outcome of—the expansion and culmination of—the imperfect sensation of the worm, the rudimentary sight, hearing and taste of the fish and reptile; and the simple consciousness which, springing from these, passed to us after almost infinite ages of slow evolution and amelioration through tens of thousands of generations of placental mammals, our immediate progenitors."

In the growth of mind, whether that of the race or of an individual, two distinct processes are observed: First, the very gradual evolution to, or toward, perfection of faculties that have already come into existence; and, secondly, the springing into existence of faculties which had previously no existence. For it is clear that no faculty came into mature and perfect life at once. Hearing and sight developed by slow degrees from the sense of touch, and in the region of the intellect conceptual life was born from ages of receptual and that from millenniums of perceptual.

Now let mind be supposed growing for countless years in the way set forth. It begins as mere excitability; to that after a long time is added what may be called discrimination, or choice and rejection of, for instance, different kinds of food. After another long interval of almost infinitely slow advance sensation appears, and with it the capacity of pleasure and of pain; then, later still, memory; by and by recognition of offspring; and successively thereafter arise reason, recognition of individuals and communication of ideas. Concurrently with these intellectual faculties certain moral functions, such as fear, surprise, jealousy, anger, affection, play, sympathy, emulation, pride, resentment, grief, hate, revenge, shame, remorse and a sense of the ludicrous, have also arisen in the nascent mind. This is the mental plane of the higher animals, which is equally that of the human being at about two years of age. Then occurs in the child the mental expansion which separates man from the higher mammals—for something like a year the child mind steadily grows from the status of the latter to the status of the human mind. At the average age of three years in the individual self-consciousness is born, and the infant, from the point of view of psychology, has become a human being.

For human being he is and as such is distinctly different from a mere animal. Elie Metchnikoff conveys an unwise, if not a false, impression when he declares in "The Nature of Man" that "Man is a

kind of miscarriage of the ape, endowed with profound intelligence and capable of great progress," and exception may be taken legitimately to a deduction of such sweeping force from the evidence of a certain trifling differentiation of a "Sunset Plant," observed by De Vries and a "Lightning Calculator" phenomenon.

Man has no reason to be ashamed of his ancestry, and assuredly there is reason for his pride as he looks back upon the path which he has traveled and perceives the advance he has made. Emerson puts the matter strongly when he says, "Man betrays his relation to what is below him, thick-skulled, small-brained, fishy, quadrumanous quadruped, ill-disguised, hardly escaped into biped, and has paid for the new powers by the loss of some old ones. But the lightning which explodes and fashions planets and suns is in him. On the one side elemental order, sandstone and granite, rock ledges, peat bog, forest, sea and shore; on the other part thought and the spirit which composes and decomposes nature. Here they are, side by side, god and devil, mind and matter, king and conspirator, riding peacefully together in the eye and brain of every man."

The phrase now so often used, "Man's Place in Nature," has become possessed of value for the reason that it is evident his place is in Nature, not in any supernatural realm. He is part and parcel of Nature, and the biological truths which apply to the smallest and most simple organism bear a relation to him, neither can he for a fractional instant escape from the domination of the Draconic laws that govern the matter of which he is composed. There is still discussion as to whether the physical frame of man differentiated itself from the parent mammalian stock at an early or recent date. All the evidence points to the remoter kinship.

"We no longer think of the human race," says Prof. David Starr Jordan, "as a completed entity in the midst of Nature, but apart from it, with a different origin, a different motive, a different destiny. Man, like the other species, is an inhabitant of the earth, a product of the laws of life; his characters are phases in the long process of change and adaptation to which all organisms are subject. From the point of view zoology, the human race is a group of closely allied species, or subspecies, undoubtedly derived from a common stock, and each species in its ramifications modified by the forces and conditions included under the several heads of variation, heredity, segregation, selection, and the impact of environment, precisely as species in other groups are affected.

"It is clear that if there is an origin of species through natural causes among the lower animals and plants, there is an origin of species among men. If homology among animals and plants is the stamp of blood relationship, the same holds true with Man as well. Man is connected with the lower animals by the most perfect of

homologies. These are traceable in every bone and muscle, in every blood-vessel and gland, in every phase of structure, even including those of the brain and nervous system."

These finger-posts to the past are given their due dignity by Charles Darwin, when he says: "To my mind it accords better with what we know of the laws impressed on matter by the Creator, that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of an individual. When I view all beings, not as special creations, but as lineal descendants of some few beings who lived before the first bed of the Silurian was deposited, they seem to me ennobled. There is a grandeur in this view of life, with its several powers having been originally breathed by the Creator into new forms or into one, and that while this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been and are being evolved."

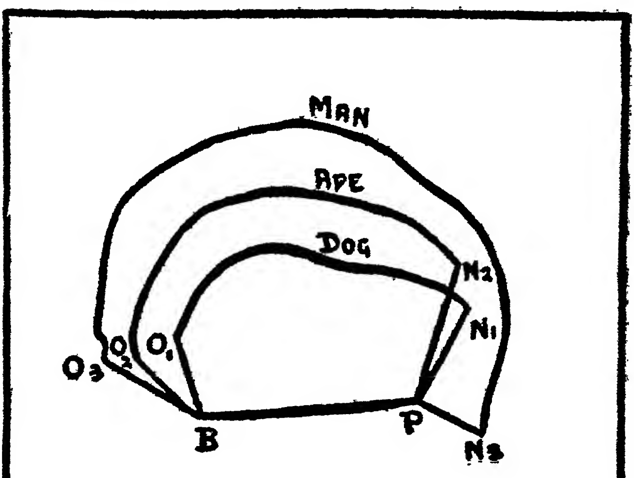


FIG. 2—Skulls of Man, Ape and Dog compared, showing that the difference between the cranial capacity of Man and Ape is greater than the difference between Ape and Dog. (*G. F. S. Elliot, modified.*)

It has been the work of the biologist to trace the functions of life in its simplest form and to show the intimate relations sustained between life in the animal and vegetable world, and it has been the path of the zoologist to depict the evolution of higher forms of animal life from the invertebrate and within the latter division of the highest order of Mammals.

The members of the Genus Homo, or Man, show structural similarities with the higher primates. Homologies of the closest sort exist, in which it is difficult to name a single point of departure. Of these the slant of the hair on the arms and body is notable.

At the same time, it is well to point out that these may be overemphasized. In the accompanying diagram it will be noted that the difference in cranial capacity is greater between ape and man than between dog and ape. To state this in another way, the dog's brain capacity is nearer to an ape's than an ape's brain capacity is to man's. The jump from ape to man is greater than the jump from dog to ape. In the diagram the line B P represents the base of the skull; N is the root of the nose, and the line B O is the plane of the foramen magnum by which the spinal cord enters the brain.

There is a more important distinction in this diagram than even the cubic contents of the cranial capacity denote. It is clear that the brains of the dog must be confined in the space P N_1 O_1 B, that the brains of the ape are confined in the space P N_2 O_2 B, and that the space P N_3 O_3 B is considerably larger, and gives more scope for the brains of the human. But the vital difference in the skull shapes of these three is the relation of N or the root of the nose.

An animal walking normally four-footed as the dog, or even generally four-footed, as the ape, must have the root of the nose well above the base of the skull in order to have a clear look-out forward. The four-footed mammal, besides, must have the line of the neck more or less in line backwards with the spine, so that the opening for the spinal cord cannot be very much more oblique than is shown in the diagram. But in man the nose is brought far down below the summit of the skull for one thing, and for another, the line at the back of the skull gives far more room. Owing to the swing forward of the line P N_3 there is no definite limit to the expansion of the brain. In the lower animals this is sharply limited by the position of the skull and the mode necessitated for carrying its weight.

Suppose in the structural comparison the skull be taken first. In the younger apes rather than in the adults is the resemblance the most striking. Yet, unexpected as it would seem, the skull of a young orang-utan presents a better facial angle, and it might be said is a more human skull than that of the skull of an Australian Bushman. While the facial angle of the adult orang is distinctly more bestial than that of the adult Australian, the young ape's skull more closely

approximates the young European child and would seem far in advance of the adult Australian were it not for the immaturity shown in the proportions.

This seems to be due to the dentition, for it is the coming of the second teeth which produces the great jaw changes, throwing forward the prognathism of the ape. Yet, even in this matter, it can be pointed out, as has been done by Metchnikoff, that the dentition of the anthropoid apes is far closer to that of man than it is to that of the other monkeys, a point originally made with much detail by Thomas Huxley and since strengthened by a host of confirmatory evidence.

"Another character," says Metchnikoff, "which shows that anthropoids are nearer Man than other monkeys is furnished by the anatomy of the sacrum. In monkeys as a whole the sacrum is composed of three, or rarely four, vertebrae, while in anthropoid apes it contains five; that is to say, just as many as in Man.

"The believers in the doctrine that the human species is essentially different from all the known monkeys have laid great stress on the difference between the foot of Man and that of the anthropoid apes. This difference cannot be denied. Man assumes the erect posture habitually, while monkeys, even the highest of them, walk on two legs only occasionally. There has followed from this a greater development of the feet in monkeys. Yet this difference ought not to be exaggerated. It has been sought to prove that monkeys are 'quadrumanous' and that their hind-legs terminate in 'hind-hands.' But it is clearly shown that in all essential respects the hinder limb of the gorilla terminates in as true a foot as that of Man." Huxley is equally assured when he says: "The hind limb of a gorilla, therefore, ends in a true foot, with a very movable great toe. It is a prehensile foot, indeed, but it is in no sense a hand; it is a foot which differs from that of Man not in any fundamental character, but in mere proportions, in the degree of mobility and in the secondary arrangement of its parts."

All the arguments dealing with structural affinity are so well worn that it is useless to recapitulate them, but it is a matter of vital interest when entirely new lines of argument, unknown to Darwin, Vogt, or even Haeckel, come to light and are found to be confirmatory of the work that they had done. These two lines of comparison are found in the embryological affinity between the anthropoids and Man and the behavior of the serum of the blood of these two mammals.

There is a great deal to be said of the homologies and similarities between the higher primates and Man, but there is another side to the picture. One of the most important points to be set forth on the separateness of Man is the fact that structural similarity of body does not necessarily prove any psychical similarity of mind. Many people

are willing to admit that the human coccyx is the rudiment of a tail, who are not willing to admit that the shortening of tails has anything to do with capacity to appreciate art, for example, or aspiration for higher things. The comparative anatomist's reply does not answer the question, for the reason that there is no definite means of ascertaining whether a rudimentary desire for "higher things," in its ethical use of the term, exists in any creature with whom Man can have no communication.

The second argument is purely scientific. It declares that, although there are numberless similarities and homologies between Man and animal, the differences are so great as to force open still wider the chasm to be bridged by "missing links." It is clear, of course, that no one seeks a missing link between Man and ape, but rather a missing link between Man and his unknown ancestor in the Eocene. Modern paleontology and archæology is pushing this ancestor further and further back. Man is regarded as far more distinctly modified from the specialized ape than he was once thought to be. The relationship of physical structure has been made more certain, it is true, but the cousinship has been far removed, so far removed indeed that it is scarcely more than the recognition of an undoubted junction in a common ancestor somewhere along the line of the mammalian stem, millions of years ago.

Consider, then, one of the great physical dissimilarities, viz., the shape of the skull and the cranial capacity resultant therefrom. There is no doubt that the weight of brain in proportion to organism is an index of intelligence, though this index is only true in mass. It does not follow that a difference of a couple of hundred cubic centimeters, more or less, will determine whether one man is cleverer than another. But, since there is no ape with as large a brain as the lowest man, and the Pithecanthropus is midway between the two; since there is no modern civilized race as low as the first known human skulls of the Ice Age, it does follow that weight of brain possesses some value as a basis of judgment, and that there is a definite gross ratio between quantity of brain and intelligence.

What are the factors which enable the human child's head to expand in such wise as to permit room for a brain case, and which do not permit the ape child's brain so to expand? The answer is illumining. In a young growing skull, the various bones which are to make up the future cranium are more or less independent of each other, though they will some day be joined together. Accordingly, the brain, which lies under a spongy arachnoid tissue beneath these bones, pushes up and up without much resistance. At a certain period of growth, the bone-making forces begin to exert their authority, and the plates come together, being divided only by "sutures" or lines of meeting. Finally, these sutures close and the skull-case is complete. In

the human being, the sutures remain open for a much longer period than in the ape, giving time for the brain to form. In addition to this, the great forward projection of the jaw of the gorilla and the heavy and massive teeth exert a powerful influence on the brain cavity.

"Imagine," says Dr. G. F. Scott Elliot, "the young gorilla chewing its food and manipulating this relatively large jaw. It is supported and worked by muscles, which are attached to the front and sides of the skull. As soon as these muscles begin to exercise full actvity, obviously they require a solid bony attachment, and hence the sutures in all this part of a gorilla's skull close at an early age. This must surely check the forward and upward expansion of the skull.

"Then, at the hinder part of the skull, there are, in the gorilla, bony ridges, to which the powerful muscles of the neck are attached. In man the corresponding muscles merely hold the head in position, but in the gorilla they have to support its weight. For this reason they are not only far stronger, but cover by their insertion a much greater proportion of the cranial surface."

It is clear, then, that if the whole gorilla skull-case were trying to expand outwards and upwards, it would be cramped and confined by the two groups of muscles encircling it, one group operating the powerful jaw, the other holding up the heavy head, which does not rest upon the vertebrae, as in Man, but has to be held by sheer muscular strain. Owing to the fact that Man's head is on an atlas and that the spine in its "Grecian bend" supports it as on a pillar, the attachment of the same set of neck and jaw muscles is so far below the widest point of the skull's circumference that the drag of the muscles actually helps brain development instead of hindering it.

The huge development of the face of the gorilla, the heavy jowl, the ferocious canines for fighting and the great crushing molars, required an enormous amount of bone-making material during their formation, and all this material was not available for the enlargement of the skull.

In Man, however, when the head was habitually carried erect, when the teeth were no longer used in terrible life and death combats against the most savage creatures of the wild, there was opportunity for the face to increase in breadth, and the restraining influence of the muscles was still further diminished.

At this point appears a human character which is absolutely wanting in every ape form. This is the chin. Even the Mauer jawbone (primitive) and the famous Piltdown prehistoric skull lack a chin; but every race of men to-day possesses this feature. The chin became necessary because, by the broadening of the skull and the shortening of the face, cross strains would be thrown on the extreme forward points of the jawbones. The bony ridge over the eye of the gorilla is due largely to the same thing, being, as it is, a means of distributing the

jar of crushing hard food from nerve centers controlling the vision.

From the mere evidence of skull characteristics alone, therefore, there is evidence that the structural differentiation of man from the mammalian stem began so far back that once more it is beginning to be doubtful whether he should be classed with the Primates at all. It may be queried whether he is not himself an Order distinct, or at least (as the writer believes) a sub-order of the Primates, as different from the Anthropoidea as these are separate from the Lemuroidea. To suggest, as does the modern accepted classification, that the difference between Hominidæ (Men) and Simiidæ (Anthropoid Apes) is no greater than that between Cercopithecidæ (Old World Monkeys) and Cebidæ (South American Monkeys) is a distortion of facts.

There is always a danger point in making alliances too close. No one will try to proclaim humanity to any other animal than Man. The attempt, however, to define precisely where the boundary is to be drawn, is a question full of fine distinctions and metaphysical subtleties. By paths that are as yet but little known Man has reached his present place and he is pressing on. He is but a creature of yesterday, on the dawn of his morning. Mankind is incredibly young and full of opportunity for change. His place in Nature is at the top, not because of what has been, but because the actual physical conformation the past has produced affords, so far as one can now determine, a vast range of possibilities for his future progress.

Man as he is to-day will not endure. There are constant modifications proceeding in him, physical and mental, each with reflex action on the other. Nothing he knows endures; the mountain is no more nearly eternal than the castle of sand the child builds upon the beach between the low tide and the high tide marks. "I believe," said the rose to the lily in the parable, "that our gardener is immortal. I have watched him from day to day since I bloomed, and I see no change in him. The tulip who died yesterday told me the same thing."

The Science of Anthropology, then, must hark back to the earlier mammalian stock for its beginning, must consider all races of men at the present day for its momentary review, and must cast a prophetic glance forward to discern what Man shall become. Its economic value lies in determining what are the lines of direction that progress is taking and in pointing out the manner to follow those lines to the end that Nature may be rightly helped, not hindered. Not that Nature needs help, but that Man, if he ignorantly endeavors to pursue a path not intended for his feet, first will suffer cruelly and at the last will be cast aside.

CHAPTER II

INDIVIDUALITIES IN STRUCTURE

It is an idiom of general use to declare that a particular person "has the ear-marks" of a certain definite type, and while this phrase probably has evolved in America from the ear-marking of cattle in the West, yet it is not the less true in a nearer instance that might be given. For ear-marks are indeed one of the many definite measurements which are not only peculiar to Man as a whole but to the individual man.

It may, perhaps, be going too far to say that the study of Anthropometry is one wherein every person is a scholar, but none the less it is most amazingly true that the actions of men's lives are modified by their intuitive or experience-taught understanding of the measurements of their fellow-beings. It has been wisely said that "had Cleopatra's nose been a little shorter it would have changed the map of Europe," and it seems not less likely to be true that had it been a trifle longer the same effect would have been apparent. Had Helen of Troy possessed a cast in the eye, where would have been the Iliad and the Odyssey, and would there have been the chivalrous loyalty in the court of Elizabeth if the Virgin Queen had been a sour-visaged shrew? Yet it must be admitted that between supernal beauty and eldritch ugliness is but the fraction of an inch here or there.

Before going into the more scientific measurements and their implications, it may be well to show that there are certain of these which are indubitably familiar to every observer. Thus a man who cannot look you squarely "between the eyes"—that is, whose eye muscles are not sufficiently under control to meet your gaze—will rarely be trusted. He is thought (and often rightly) evasive, underhand and untrustworthy. Where the eyes are large and lustrous an affectionate disposition is expected, when they are steely blue and extremely rapid in their glances from object to object, quickness of wit and instancy of decision are encountered.

How generally are the measurements of the lips taken in such hasty decisions. Ripe, red lips, moist and partly open, seem to convey an invitation to dalliance which is certainly absent in the thin, hard, dry line of the angular and embittered spinster. Likewise a mouth kept partly open most of the while is often a sign of vacuity of

mind and uncomprehending surprise, while a firm, determined set of the lips and of the chin reveals a character thoroly comprehending the goal sought and insistent on securing the point of attainment sought. In contrast to this, again, the receding chin is taken to imply mental weakness and lack of purpose.

So a low, receding forehead and a development of the back of the head is so well known that in common speech it is called a "criminal head," while if it be coupled to a mowing of the jaw and a certain glassy stare in the eyes it is interpretative of some forms of idiocy. Even the eyebrows play their part, and it is familar to hear of frowning eyebrows implying fierceness of temper, of supercilious eyebrows implying a character prone to the use of the critical faculty, and tilted eyebrows are often esteemed the sign of an unready nature. The list could be multiplied to great length, and these merely have been mentioned, not in the sense that scientifically speaking they do really portray the characters to which they have been assigned, but to show that a relation of character to physical measurement is popularly assigned.

A still more striking evidence of this is seen in the matter of resemblances. The actual variances of measurement between two brothers or two sisters often are very slight—so far as the face goes, they require the most exact instruments to record them; yet the eye at the same time perceives a similarity and a difference. But for this ability of the eye to grasp readily the infinitesimal differences in features, all family life would come to a standstill; the husband would not know the wife nor the wife the husband, and neither children nor parents could be sure of their relationship.

Commerce and trade would come largely to a standstill, for there could be no system of credit if the buyer and the seller were unable to recognize each other. It forms an interesting speculation, indeed, to try and devise a world which should be in all respects as this, yet lacking the anthropometrical sense. It is certain that it would modify profoundly the civilization of to-day.

The race question would take on a new aspect, for gradations of color really belong to anthropometry and certainly physiognomic comparison also. The Chinaman and the Negro and the Caucasian are easily told apart, but only because of color and of measurement. Nay, even the difference between a man and an ape, between an ape and a dog and so forth are again merely matters of measurement.

In Ethnology, generally, no little use will be made of anthropometrical measurements, for the reason that they afford a true basis for divisions of races. Thus the oblique slant of the eyes is a Mongolian sign, the prognatous jaws and intumescent lips reveal the Negro, and the high facial angle indicates the Caucasian. To touch on other structural differences, may be mentioned the well-known facts

of the greater length of arms among the negroes and the hindward projection of the heel in a manner similar to that of the anthropoid apes.

Of recent years, however, a new value has been given to anthropometry by its use in criminology, or the dealing with the various types of criminals that infest society. This, because it has been carried to its highest degree of efficiency, as well as because most of the origination and development of the plan was done by Alphonse Bertillon, is known as the Bertillon system.

An admirer of Bertillon, Prof. Persifor Frazer, went so far as to declare that the system is the answer to the question, "Of what use is Anthropology?" This is an extreme viewpoint, for Anthropology has a score of other avenues of economic value, but it contains enough truth to point out the exceeding value of such measurements in Criminology. Not the least important of the contributions of the Bertillon system has been its vast accumulations of materials as a basis for scientific research along eugenical lines.

If the aphorism be true that "genius is the capacity to take definite pains," Bertillonage is an example of the highest genius, for its successful application depends upon a delicate unperturbed appreciation of physical sensations on the part of the observer, a scrupulous accuracy in recording observable data, and the use of all the precautions known to original investigation by repetition of measurements and readings to avoid possible error.

Broca, a member of the first Société d'Anthropologie, of Paris, proposed a color scale for describing the eyes and skin of different races of men. The characteristics which he regarded as most valuable in distinguishing races were, first, the color of the skin; second, the structure of the skull and their importance in the order given. His eye tests, once abandoned, have been taken up again.

According to Retzius' method, very generally adopted by anthropologists, the longer diameter of the skull from front to back is assumed as 100. If the shorter diameter measured above the ears is less than 80 on this scale, the skull is called dolichocephalic (long-narrow headed); if more than 80, brachycephalic (short or round headed). From 75 to 80 in the transverse diameter he called mesocephalic. Negroes have 72, Europeans 78, and Tartars 88, in this measure. The application by M. Bertillon of these methods was for the identification, not of great groups of the human family—races—from each other, but of an individual from every other individual, and arose from the urgent need of the law courts to know whether they were dealing with old offenders (recedevistes), or whether an arrested man actually had not been previously before them.

M. Bertillon's system is divided into, first, a means of identifying an individual with absolute certainty, from careful measurements

taken by skilled agents, and, second, a ready means of recognizing an individual in a crowd from a description or from observations previously taken. One supplements the other, while each is useful independently of the other.

The principle upon which the measurements are based is that no things are absolutely identical, however similar they may seem. This is especially true of organic objects which grow, because it is unthinkable that two different and separate beings could be, during a number of years, subjected to exactly the same forces, and should present to these forces exactly the same resistances. Whatever it be, whether two coins struck from the same die, twins who have been fed and nurtured similarly, even two drops of water taken from the same source, a sufficiently minute examination will inevitably disclose differences which will be greater and more numerous the more searching and careful is the investigation. It is only necessary then to obtain a sufficient number of data from each individual to place upon record a description which will differ from that of any other individual analogously made.

This identification is confined to the two measurements of the head with callipers fixed successively to the figures given in the description already on file. These two data taken and corroborated to a millimeter (1/25 inch) are amply sufficient to determine whether or not the prisoner has told the truth. It is thus at once seen whether the same individual is present, and if so no further measurement is made. When the same offender has been identified five times he is banished.

As rapidly as possible those who are subjected to a further examination are called into the large adjoining room where three sets of measurements can be undertaken at the same time. In each case the same agent obtains the following anthropometric measurements, the portrait parlé description, and the peculiarly characteristic marks, which are recorded by a clerk occupying an elevated desk very much as the measurements are taken in the better class of tailor shops.

The Long Diameter of the Skull.—This is obtained by means of adjustable callipers with a binding screw to fix the arms at any position. The measure is made from the cavity at the root of the nose to the point of greatest protuberance of the occiput. Two measures are made to control each other.

Transverse Diameter of the Skull.—This is taken by means of the same callipers and is the maximum distance apart of the parietal bones which are situated above the superior border of each ear.

The length of the middle finger, the span with both arms outstretched, the length of the left forearm, the height, the height of the trunk and the length of the ear are all determined. The Bi-zygomatic Diameter has in part replaced that of the right ear. It is taken by means of the same callipers, between the osseous bands which termi-

nate above the auditory canal and behind the cheek bones. In French adults it varies between 137 mm. and 138 mm. (about 5.39 inches).

"It is evident at the first thought," says Prof. Frazer, "that the most permanent data will be found in those parts of the body which undergo the least change; in other words, the bony structure; and of all these the skull, which from an early age, in spite of its twenty-two component bone-plates, is virtually a single large bone, proves the most available for identification because important artificial alteration of its dimensions is almost or quite impossible." (The skull of the adult of course is referred to here, as the savage deformations of the skull are done in childhood.) The pivotal point of the Bertillon measurements is therefore the skull and the relation to each other of its anteroposterior and transverse diameters.

Two other means of identification of the highest importance have been added to the anthropometric measurements of M. Bertillon, the finger-prints and the shades of color in the eye.

The study of the finger-prints is perhaps the most picturesque of all the Bertillon points. It is an addition to the system and is so recognized, and the credit seems to be assigned to Sir William Herschel when he was Collector of a district in Bengal. Altho it was handled there in modern methods, the true importance of it did not appear until 1888 when Francis Galton, having given it extensive study, announced to the scientific world the conspicuous value of the system and illustrated his arguments with examples that allowed of no further question. The setting forth was exhaustive and conclusive.

Altho Galton is on record as having said that his attention was drawn to the matter by a personal investigation of the Bertillon system, the French bureau for some years paid no attention to it until M. Bertillon saw that it would afford an absolutely final support in the verification of criminals. Galton's system was slightly modified, and a nomenclature and method arranged which is now complete in every detail. To this end the four vowels "e," "i," "o," and "u," are used to indicate the four types into which the patterns of the finger prints are divided. Loops resting on the usual triangle of intersection near the middle of the impression extend from left to right downward; their closed ends being above and to the left, and the free ends descending to the right. To justify the designation there must be at least two such loops.

The type "i" is that pattern where at least two ridges indicated by black lines in the impression have their closed ends to the right, above the triangular places of intersection, forming an oval, or spiral, the latter either concentric or as volute.

The type "o" is that where the digital lines appear to the number of at least 4 between the little triangular patterns marking the central point of each finger tip; and their form is oval, spiral, or volute.

The type "u" is that pattern in which the lines are superposed in the form of an arch, flat near the bottom and higher on top.

An interesting practical application of this method appeared in the mysterious Steinheil-Japy murder case which had been agitating Paris in the winter of 1908. In this instance the invisible network of greasy

Fig. 8—Types of Finger Print Patterns

exudation from the papillary ridges of various hands which grasped a bottle of cognac had been traced to the possessors of these hands, the prints being dusted with finely powdered white lead.

Another case, taken at random among thousands, was as follows: On April 30, 1906, a man was arrested and measured under the name of Giard. On September 4, 1908, a prisoner was measured, giving his name as Giraut. Tho 27,739 persons had been measured in the

interval he was identified by the finger-prints in less than five minutes.

The Examination of the Left Eye.—The eye is a means of identification as important, in M. Bertillon's estimation, as the marks of the finger prints. The color does not change with age. So far as its color is concerned, M. Bertillon asserts, the eye is unchangeable from birth to death. M. Bertillon has made a table of seven categories of color. The categories are based on the increasing intensity of the yellow-orange pigment. The pigment is a reddish or brownish yellow animal matter which gives to the eye diverse tints. When the pigment increases in quantity in an iris, the eye from the point of view of its color, and of the number in its class, increases also.

In other words, the more pigment an eye contains the more it appears dark, and close to the extreme type of pure horse-chestnut color. Eyes called unpigmented are not deprived of all color, but are uniformly blue, and the opposites of the pure horse-chestnut brown color. This type of eye is found among the Slavs and the people of the North, the other type among the negroes, the Arabs, and more generally the dwellers in the South.

The function of the anthropometric service is to obtain from the prisoners brought to it a certain number of osseous measurements, using the figures thus obtained as a basis to classify the photographs of individuals, after the manner of a classification of flora, etc., to enable one ultimately to find, in a collection destined to contain several hundred thousand specimens, the portrait of an old offender who has concealed his identity under a false name and a disguise.

Suppose the collection to contain sixty thousand records. The first division is based on the longer diameter of the skull. In all cases the order is from small to great. Then the division containing records of these would be: short heads, 20,000; medium heads, 20,000; long heads, 20,000.

Each of these three divisions of 20,000 is further divided into: narrow heads, 6,000; medium heads, 6,000; broad heads, 6,000.

Each of these three divisions of 6,000 is further subdivided into: long middle fingers, 2,000; medium middle fingers, 2,000; short middle fingers, 2,000.

Each of these last divisions of 2,000 is further subdivided into: short left foot, 600; medium left foot, 600; long left foot, 600.

These again into: long left forearm, 200; medium left forearm, 200; short left forearm, 200.

These further into: small little finger, 60; medium little finger, 60; long little finger, 60.

These into: long right ear, 20; medium right ear, 20; short right ear, 20.

These into heights: short, 6; medium, 6; tall, 6; and these six remaining from the 60,000 original cases are further differentiated by

the color of the eyes. So that but a few minutes would elapse from the first glance into the head-length box till the agent had traced the individual whose record-slip was given to him down to the ear division, and selected by the eye-color determination which of the six slips if any corresponded to that in his hand.

When in addition the finger prints are available, it is clear that possibility of mistake is eliminated. In more than 2,300 recognitions thus transmitted to the trial magistrates not a single one has caused the confusion or embarrassment which a mistake would have been sure to occasion.

M. Bertillon has strictly forbidden his employes to inform the interested individual when he has been identified. A few notes are taken and he is dismissed to the depot, but the facts are put into the possession of the magistrate who is to try him, and this will explain the frequent dramatic sensations produced. The prisoner is arraigned before the magistrate. He has answered that his name is Jean Bourdet, a carpenter, living in the Rue Mesnil, that he is unmarried, and twenty-four years old. Whereupon the genial justice replies: "Your name is Eugene Tridot; you were arrested for highway robbery and attempted assassination on June 17, 1902; you were also imprisoned for beating your wife almost to death; you were born in Lyons, are thirty-seven years old and have served three terms of imprisonment; this is your fourth appearance and last chance; your present punishment must bear relation to your former crimes, and if you are ever again in the hands of justice, banishment inevitably will follow."

Professor Frazer touches a point of vast importance when he reveals the potency of the Bertillon system not only in identifying criminals, but in convincing offenders against society that recognition is inevitable and penalty swift and sure; while, even more than this, it becomes a most efficacious prevention of crime. When it is no longer possible to dodge the law, illegality diminishes. Again, the same writer points out: "If the identification be so perfected, and so universally adopted, that recognition of a person who has been Bertillonized is positively certain, will it not be possible so to modify the penal legislation that the trials and condemnations of criminals shall proceed to the ultimate punishment of the guilty without the use of names at all? In this way the innocent parents, brothers and sisters of a degenerate may be spared the added humiliation and suffering of seeing the name they bear and have tried to make honorable associated with some revolting or contemptible crime."

This is but one of the avenues of advancement which the study of Anthropometry affords. It possesses especial force because of its practical nature and the intense amount of energy inherent to it in the suppression of crime, in the advancement of civilization and in the general welfare of mankind.

CHAPTER III

THE UNITY AND VARIETY OF MAN

Race hatreds evoke many curious problems. Many of them have absolutely no assignable reason for their existence, others are due to the contempt of a powerful race for one which has been less successful in the struggle of life, others again are the result of hostilities born out of national or commercial rivalries. Only a few depend upon an utter difference in racial stocks, and in this, intermarriage is associated with hatred and bitterness. Yet, by the law of Fertility, which physiologists now accept as a leading test of varietal and specific difference, all races of Man are, and have been for ages, permanently fertile, while such a condition does not exist, and cannot be forced to exist, between Man and any other species.

This possibility of miscegenation—as the interbreeding of highly disparate stocks is called—is extremely obvious in North America. Such questions are the warp and woof of Ethnology. Were it not so, this science would have no problems to consider; for on the one hand and on the other would be races complete, their respective characteristics continuing without any direct change—and there would be an end of it. But Ethnology faces one of the most complex of problems, since the entire readiness of one race to absorb and of another to be absorbed, coupled with the persistence of certain peculiarities, obliterates all hard and fast lines of division and reveals the imperceptible gradations by which one race shades into another.

If it were feasible to produce a map of the populated world wherein the particular color scale of each district could be painted in, all following a definite average, the colors ranging from the flesh color of a northern Scandinavian to the almost jet black of certain Negro tribes, such a map would appear greatly mottled owing to the manner in which certain settlements of variant races have strayed in. Viewed from a fair perspective, the shading from fair to dark would reveal blending everywhere and harsh lines of division nowhere.

This same difficulty becomes apparent also in the remains of Prehistoric Man, altho this point is often curiously ignored. Thus, it does by no means follow that the discovery of a certain paleolithic skull in a certain locality presupposes the existence of a race of men markedly similar. This objection ceases in the later neolithic times, when an

abundance of remains yields definite averages. Certain discoveries, however, point to an earlier physical form of Man than any which are now known, and these have formed the basis for much anthropological argument. The men of Neanderthal, of Spy, of Laugerie-Basse, and the latest of all—the Pithecanthropus Erectus, or "the fossil ape-man of Java"—have formed the basis, respectively, for an immense amount of description, of comparison, and of surmise.

The discoveries of the actual osseous remains of primitive man are of vast importance, but they are very few. Thus, for example, the Pithecanthropus Erectus, around which so much comment and criticism has gathered, is deduced merely from the roof of the skull, and one tooth and one thigh bone which may or may not have been part of the same creature. A. H. Keane, in his "Ethnology," has classified the remains worthy of credence as follows:

"Trinil (Pithecanthropus Erectus), found on the left bank of the river Bengawan, Java. Roof of skull, an upper molar and a femur, found (1894) by Dr. Eugene Dubois in pleistocene (?) bed 12 to 15 meters below the surface. Showing characters intermediate between gorilla and Neanderthal, but distinctly human, low depressed cranial arch; 'the lowest human cranium yet described, very nearly as much below the Neanderthal as this is below the normal European'; femur quite human; tooth very large but more human than simian.

"Neanderthal, a brain-cap, two femora, two humeri, and some other fragments; remarkable for its flat, retreating curve; the most apelike skull, next to the Pithecanthropus Erectus.

"La Naulette, Belgium, an imperfect lower jaw; simian character very pronounced in the extreme prognathism and alveolar process.

"La Denise, France, two depressed and retreating frontal bones, glabella of one very prominent, recalling the Neanderthal; that of the other also prominent, and separated from the retreating frontal bone by a deep depression.

"Brux, Bohemia, a brain-cap and other bones; frontal region and flat, elongated parietals like those of Neanderthal and Eguisheim, but superciliary bosses larger than the latter.

"Spy, Belgium, two nearly perfect skeletons (man and woman); enormous superciliary ridges and glabella, retreating frontal region; extremely thick cranial wall, massive mandibular ramus with rudimentary chin. Large posterior molars; divergent curvature of bones of forearm; tibia shorter than in any known race, and stouter than in most; tibia and femur so articulated that to maintain equilibrium head and body must have been thrown forward as in the largest apes.

"Galley Hill, England, nearly perfect skeleton, skull extremely long, narrow, and much depressed; glabella and brow ridged, prominent; forehead somewhat receding; height about 5 ft. 1 in.; altogether, most nearly related to the Neanderthal. Spy, and Naulette types.

"Podbaba, Poland, fragment of skull; approaches the Neanderthal type.

"Predmost, Bohemia, fragments of skeletons of six persons, similar to Neanderthal type; that of man wonderfully complete, and of gigantic proportions.

"Marcilly sur Eure, Belgium (?), part of skull, also of Neanderthal type.

"Arcy-sur-Eure, Belgium (?), lower jaw, somewhat modified Naulette type.

"Olmo, Italy, skull; above that of Neanderthal. A doubtful find.

"Eguisheim, Germany, part of skull, prominent superciliary ridges, frontal region broad but retreating, sutures simple and nearly effaced.

"Laugerie-Basse, France, one skeleton (male), two skulls (female); thick parietals; cranial capacity above the modern average in the male and in one female skull, but in the other female very low.

"The foregoing," says Keane (writing before the recent discovery of Chapelle-aux-Saints), "belong to various paleolithic epochs, and while all, without exception, are dolichocephalic (index ranging from about 70 to 75), the distinctly low characters show progressive modifications in the direction of the higher neolithic and modern types." Keane goes on to point out that both in France and England, following a large number of finds, the earliest men "appear to have been of long, then of medium, and lastly, in some places, of exclusively round-headed type (of skull)."

If, then, the early times reveal the possibilities of indefinite crossings and intermarrying among variant races, it is next in order to point out that such intermarrying is permanent, and that, far from producing a weak breed, it possesses a definite strength of its own. The statement made by Dr. Robert Dunn, in his "Unity of the Human Species," that "half-castes very generally combine the best attributes of the two races from whence they originate," might be somewhat qualified.

In the far north the Dano-Eskimo half-breeds of Greenland are becoming the dominant races; in Canada the famous French Canadian-Algonkian voyagers were among the hardiest races ever seen; in the United States the high birth-rate of mixed negro and white blood is well known; and in Brazil the cross between the first Portuguese immigrant and the aborigines, the so-called "Paulista" half-breeds, are "the most vigorous and enterprising section of the community."

In Africa, the "bastaards," or Hottentot-Dutch cross—could more dissimilar races be selected!—form flourishing communities in Griqualand, and are known as Griquas; the Negro-Hottentots have crossed to form the Gonaquas; the Gallas are Negro and Hamite; the Abyssinians are Negro, Hamite and Semite.

In Asia, the Baltis are part Mongol and part Aryan, the Dravidian

aborigines mix with the Aryans to their profit, and the Franco-Annamese in Cochin China, known as the Minh-huongs, are said by M. Morice to be increasing in number, to be well adapted to climate, and to possess powers finer than their former savage race. Certain of the Oceanic Islands, such as the Philippines, have all the four varieties of the human species intermingled.

The famous Pitcairn Island mutineers are a historic case. In 1789 the mutineers from an English ship, the "Bounty," nine in number, all English, were marooned on Pitcairn Island, with six male and fifteen female Tahitians. Strife was constant over the possession of the women, and when the island was next visited, four years later, five of the English sailors, all the Tahitian men, and five of the Tahitian women had been killed. The four remaining Englishmen had made a partition among themselves of the ten Tahitian women, realizing that life would be impossible if every man's hand was against his neighbor. In 1825 the colony had increased to 66 persons, and in 1891 to 120. The islanders are very dark in complexion, but possess Caucasian features; their intelligence is of a fine order, and their physical resistance is high.

"It may be concluded on inductive evidence," comments Keane, "that all the Hominidae (Man) are, and always have been, permanently fertile with each other. Eugenesis (indefinitely fertile miscegenation) is the norm, and to it must, in fact, be attributed the endless varieties of mankind, which may be said to have almost everywhere supplanted the few original fundamental stocks."

The first serious attempt at a systematic grouping of the races of Man was made by F. Bernier (1625-1688), who distinguished four types: the European white, the African black, the Asiatic yellow, and the northern Lapp! Linnaeus (1738-1783) followed with his "Homo monstruosus," "Homo ferus," and "Homo sapiens." The "Homo ferus," being dumb, and covered with hair, answers somewhat to Haeckel's "Homo alalus," while the group "Homo sapiens" comprises four varieties: the fair-haired, blue-eyed and light-skinned European; the yellowish, brown-eyed, black-haired Asiatic; the black-haired, beardless, tawny American; the black, woolly-haired, flat-nosed African. Blumenbach (1752-1840) followed with his five varieties bearing a nomenclature that still largely persists: "Caucasic," "Mongolic," "Ethiopic," "American" and "Malay." But Blumenbach later (1795) fell back on Linné's four varieties, which, however, he distributed somewhat differently, assigning to the Caucasic most of Europe, Cis-gangetic Asia and the region stretching northward from the Amur basin; to the Mongolic Trans-gangetic Asia north to the Amur "with the islanders and great part of the Austral lands"; to the Ethiopic, Africa; and to the American, all the New World, except the northern

coastlands—that is, the Eskimo domain—which he includes in the Mongolic division.

Then ensued a period of orthodox reaction against the Lamarckian ideas headed by Cuvier (1773-1838), who held by fixity of species, but inconsistently admitted three races, the Caucasic, Mongolic and African, supposed to answer to the biblical Japhetic, Semitic and Hamitic families. In 1801, Virey (1775-1840) reduced Cuvier's three divisions to two distinct "species," white and black, each with three main "races" or subspecies, which again comprised a number of secondary groups. But this could not satisfy thoro-going polygenists, such as Desmoulins, who started eleven human species in 1825, and the next year raised them to sixteen; Bory de Saint-Vincent, who in 1827 discovered fifteen species, including such nebulous groups as "Scythians," "Neptunians," "Columbians"; lastly, the American school, which, in the hands of Morton, Gliddon, Knox, Agassiz, and others, brought about an inevitable reaction by threatening to increase the number of species indefinitely. Other groupings, which were marked by greater sobriety, and which still possess some historic interest, were those of Hamilton Smith (Caucasic, Mongolic, Tropical); Latham (Japhetic, Mongoloid, Atlantides); Karl G. Carus (four divisions somewhat fantastically named "Nachtmenschen," "Night-men," the Negro; "Tagmenschen," "Day-men," the Caucasian; "östliche Dämmerungsmenschen," "Men of the eastern twilight," Mongolo-Malayo-Hindu peoples; and "westliche Dämmerungsmenschen," "Men of the western twilight," the American aborigines); and Peschel (Australian with Tasmanian, Papuan, Mongoloid with Malayo-Polynesian and American, Dravidian, Hottentot with Bushman, Negro, Mediterranean—*i.e.*, Blumenbach's Caucasian).

A fresh element of confusion, which still clings to ethnological studies, arose out of Frederick Schlegel's little treatise on the "Language and Wisdom of the Hindus" (1808), which was later declared by Max Müller to have revealed a new world, and to have shown what unexpected services Anthropology might derive from the science of language. The extreme views of the ensuing philologists were countered by Nott, Gliddon and Knox, who suggested an unlimited number of human species and varieties.

Meanwhile, the way had been prepared for a more rational treatment of racial diversity by Dr. James Cowles Prichard, who, not without reason, is by many regarded as the true founder of ethnology as a distinct branch of general anthropology. At least, suggests Keane, he may share this honor with Buffon, who, so early as 1749, had undertaken "l'Histoire Complète de l'Homme," as a part of his great work on the Animal Kingdom (1749-1788).

His "Crania of the Laplanders and Finlanders," continued by the more solid work of the elder Retzius in the same field, gave a fresh

impulse to craniological studies which had already been cultivated by Morton, and on which Geoffroy Saint-Hilaire based his four fundamental types: orthognathous, eurygnathous, prognathous and euryprognathous (1858). Thus were laid the foundations of the comparative study of the Hominidae based on their physical characters, a line of inquiry which, in the hands of Broca, de Quatrefagas and Hamy ("Crania Ethnica"), Topinard, Virchow, Kollmann, Mantegazza, Pruner Bey, Barnard Davis, Beddoe, Huxley, Thurnam, Turner, Rolleston, Flower, Macalister, Garson, Cope and others, has led to fruitful results.

Among these latter it is notable that a great emphasis is laid upon the hair. Thus Ernst Haeckel made a division into two, the Ulotriches, or Wooly-Haired, and the Lissotriches, or Lank-Haired, the former of which he divided into Tufted and Fleecy, and the second into Straight and Curly. De Quatrefages remained faithful to color, and divided the Human race into White, or Caucasic; Yellow, or Mongolic; Negro, or Ethiopic. Huxley followed the division of Bory St. Vincent, of Ulotrichi, Woolly-haired, and Leotrichi, Smooth-haired, and divided the latter into four divisions on the ground of color. Broca made a tripartite division on the basis of hair, Straight-haired, Curly-haired and Woolly-haired, divided that again by the shape of the skull, and then subdivided on the basis of color. Müller followed the line of Huxley.

From a general survey of the various schemes it appears that special, if not paramount, importance is given by these systematists to the three elements of complexion, character of the hair, and shape of the skull. Precedence may be claimed for color, at least as the element which occurs first to the observer, and on which, probably for that reason, the first groupings were determined. It appears that the pigment, or coloring matter, situated chiefly in the "rete mucosum," or lower layer of the cuticle, which was formerly supposed to be peculiar to the Negro, is really common to all races, only more abundant, and of darker hue, in the Negro, the Papuan, Australian and Oceanic Negrito. Nor is there any necessary correlation between this darker hue and other Negro characters.

It is important to note that the palms and soles of the Negro are never black, but always yellowish, that the dark pigment is wanting in the Negro fetus, and that Negro children are born, according to Waitz, "of a light gray color." Hence it might be inferred that the dark color, with which a thicker skin is correlated, is a later development, an adaptation of the organism to a hot, moist malarious climate, in which the Negro thrives and the white man perishes.

"Thus color, taken alone," says A. H. Keane in his "Ethnology," "cannot be regarded as an entirely trustworthy test of race, the less so that even blackness is not an exclusively Negro character, but com-

mon also to many eastern Hamites (Agaos, Bejas, Somals, Gallas), and to numerous aborigines of India. Nevertheless, it is far too important a factor to be overlooked, and taken in combination with other characters will lead to satisfactory results. Altho the transitions, as in other physical traits, are complete, there appear to be about six primary colors to which all the human groups may be referred, as under:

"Black.—African and Oceanic Negroes; Australians; Tasmanians; some aborigines of India and America; Eastern Hamites.

"Yellow.—Mongols; Indo-Chinese; Japanese; Tibetans; some South Americans; Bushmen; Hottentots.

"Brown.—Polynesians; Hindus; Plateau Indians of America; many Negritoes; Fulahs.

"Coppery red.—Prairie Indians ("Redskins").

"Florid white.—Northern Europeans; Lapps; Finns; Xanthochroid Caucasians generally.

"Pale white.—Southern Europeans; Iranians; many Semites and Western Hamites; Melanochroid Caucasians generally."

The hair, if not regarded as of more importance than the complexion, has steadily risen in favor with systematists, especially since a paper by Pruner Bey "On the human hair as a race character, examined by the aid of the microscope," before the Paris Anthropological Society, 1863. Since then this element, previously little attended to, has been made the base, or leading character, in the groupings of some of the most eminent recent ethnologists. The reason is that both color and texture of the hair are found to be extremely constant characters, resisting time and climate with wonderful tenacity, and presenting remarkable uniformity throughout large sections of the human family. Thus all the American aborigines, from Fuegia to Alaska, as well as most of the Mongoloid, Malay, and Eastern Polynesian peoples, are invariably distinguished by the same black, lank, somewhat coarse and lusterless hair, round, or nearly round, in transverse section. No other single physical trait can be mentioned which is to the same extent characteristic of several hundred millions of human beings distributed over every climatic zone from the Arctic to the Antarctic waters, and ranging from sea-level (Fuegia, Mackenzie estuary) to altitudes of 12,000 and even 16,000 feet (Bolivian and Tibetan plateaux). So, also, short, black, woolly, or at least crisp, or frizzly hair, elliptical and even somewhat flat in transverse section, is a constant feature of the Negroes, Hottentots, Bushmen, Negritoes, Papuans, Melanesians, Tasmanians, in fact of all the distinctly dark Negroid populations, say, of 150 million members of the human family. Lastly, hair of intermediate types, black, brown, flaxen, red, smooth, wavy or curly, and generally oval in transverse section, prevails among

both sections of the Caucasic division, which may now be estimated at 700 or 800 millions.

From Pruner's microscopic studies it appears that, apart from its color, the structure of the hair is threefold: 1. Short, crisp or fleecy, usually called "woolly," elliptical or kidney-shaped in section, with mean diameter 20:12 in hundreds of millimeters; no perceptible medullary tube, and often relatively flat, especially in Papuans; color almost invariably jet black; characteristic of all black races except the Australians, and aborigines of India. 2. Long, lank, of the horse-mane type, cylindrical, hence round, or nearly so, in section, with diameters either about 24, or, if elongated, 27:23; distinct tube, filled with medullary substance; color mainly black or blue-black; characteristic of all American and Mongoloid peoples. 3. Intermediate, wavy, curly or smooth; oval in section, with long and short diameters 23:17 or 20:15; distinct tube, but empty or diaphanous; all colors from black through every shade of brown to flaxen, red and towy; characteristic of most Caucasic peoples, but in the eastern Hamites and some others developing long, ringletty curls.

The third basis customarily used in Modern Ethnology is the relative size of the skull. The importance of this measurement is because the relation of mental power to cranial capacity is close. "Casts of the interior of the skull," says Romanes, "show that all the earlier mammals had small brains, with comparatively smooth or unconvoluted surfaces; and that, as time went on, the mammalian brain gradually advanced in size and complexity. Indeed, so small were the cerebral hemispheres of the primitive mammals that they did not overlap the cerebellum, while their smoothness must have been such as in this respect to have resembled the brain of a bird or reptile. This, of course, is just as it ought to be, if the brain, which the skull has to accommodate, has been gradually evolved into larger and larger proportions in respect of its cerebral hemispheres, or the upper masses of it, which constitute the seat of intelligence."

The skull measurement is taken from between the eyebrows to the extreme back of the skull, and the transverse diameter from side to side. The distances from between eyebrows (glabella) to extreme point at back (occiput) being taken at 100, the width of the head is then compared with that, and the proportion stated in percentage terms. The extremes appear to lie between 61.9, a Fijian, and 98.21, a Mongolian, and from 70 to 90 will include all save a few races. Where the width is 75, or under, it is termed Dolichocephalic or Long-Headed; from 75.01 to 77.77, Subdolichocephalic, or approximating Long-Headedness; from 77.78 to 80, Mesoticephalic, or Medium-Headed; from 80.01 to 83.33, approximating Broad-Headedness; from 83.34 upward, Broad-Headedness.

Thus, among the Long-Headed will come the Kai-Colos of Fiji,

65; the Eskimo, 71.77; the Neanderthal man, 72; the Hottentot and the Bushman, 72.42; West African negro, 73.40; the Arab, 74.06. Among those who approximate Long-Headedness come the Neolithic men, 75.01; the ancient Egyptians, 75.78; the Anglo-Saxons, 76.10; and the Chinese, 77.60.

Among the Medium-headed are the Ancient Gauls, 78.09; Mexicans, 78.12; the Dutch, 78.89; North Americans, 79.25; Hawaiians, 80. The next division leading to the Broad-Heads contains the Mongols, 81.40; Turks, 81.49; Italians, 81.80; Finns, 82; and South Germans, 83. Then in the Broad-headed races are found the Indo-Chinese, 83.51; Bavarians, 84.87; Lapps, 85.07; Burmese, 86; Armenians; 86.5; Peruvians, 93.

The famous "facial angle," or the means of determining gnathism, is of great importance. Refraining from hyper-detailed statements of the modes of measurement, it may be said that gnathism is the greater or less projection of the upper jaw, which itself depends upon the angle made by the whole face with the brain-cap. Generally speaking, facially it is the projection of the jaw beyond a perpendicular line dropped from the forehead. The divisions between the races are clear and sharp. Thus the white races (pethognathous) range from 89° to 81.30°, the yellow races (mesognathous) from 82° to 76.58°, and the black races (prognathous) from 69° to 59.5°.

Stature is also easily recognized, but it is more variant and the range between individuals of a race is great. Despite this, however, certain distinct classifications do appear and the Patagonian Giants and the African Pigmies occupy opposing ends of the scale. Excluding the abnormal dwarfish and gigantic specimens of the showmen, the height ranges from between 4 feet 7 inches and 6 feet 2 inches with a mean of 5½ feet; this for the male adult, from which for the female must be deducted about 8 per cent. in the tall and 5 per cent. in the short races. Broca and Topinard show that all the Negritos are dwarfish, the true Negroes tall, the Mongols rather below the average, the Americans extremely variable.

The nose also is a well-known characteristic, as the Hebrew illustrates. It may be normally thin, prominent, long, straight or else convex (arched or hooked) in the higher races, in the lower short, broad, more or less concave and even flat. A careful study of this organ shows almost better than any other the coördination of parts in the facial features generally. Thus the small flat concave is usually correlated with high cheek-bones and narrow oblique eyes (Mongol); the short with wide nostrils and depressed root, with everted lips and bombed frontal bone (Negro); the short with blunt rounded base and depressed root, with heavy superciliary ridges and long upper lip (primitive Australian and Tasmanian); the large, straight or arched, with regular oval features (Semite and European).

There is, however, a distinct line between the study of Mankind in races and in peoples, just as there is a distinct difference between the study of Man as the individual and as the race. The study of the individual is what has been called Physical Anthropology, the study of the race has been called Ethnology and the study of a people might well be called Ethnography. Yet Man is always a member of a community and can never be considered without reference to that relation, and it would be a false presentation to show him as an individual and as a race without also depicting his position as a member of an ethnographic group.

CHAPTER IV

THE RACIAL DIVISIONS OF MAN

The consideration of the physical characteristics and measurements of Man, it will be noted, have brought to light some very striking coincidences with regard to the racial divisions made by anthropologists. Thus, for example, in cranial capacity, in gnathism, in physiognomy, in hair and in many less obtrusive ways it is seen that there is a distinct line of difference between the white race and the black. A man whose color is black, whose hair is blue-black and flat in transverse section, whose jaws are prognathous, whose lips are intumescent, whose nose is broad, flat and with diverging nostrils, and whose teeth are large, cannot be regarded as similar to a man whose color is white, whose hair is flaxen with elliptical section, whose jaws are orthognathous, whose nose is arched or straight with nostrils not diverging and whose teeth are small. When, in addition to this, the speech, the customs, the religion and the temperament are diametrically opposite, it is clear that these concordances definitely separate one race from another.

When the question is raised, however, as to how many races there are in the human species, it must be admitted that a definitive answer is hard to give. There are certainly three distinct types and probably a fourth, but it seems equally certain that one of these first three is a thoroly mixed race, being based largely on a type that has almost disappeared. The reference is to the Caucasian race, which carries on many of the characteristics of an Archaean white race, now extinct.

There are two races, however, whose case is simple and clear, the Yellow race or the Mongoloid and the Black race or the Negroid. There has not been any scheme proposed in any age which put these two races together in a classification that has gained even momentary support among scientific men. Whether color, skull, hair, language or customs be brought to bear, these two races remain apart. It is certain, then, that of the human species there are at least two divisions, yellow and black, or Mongoloid and Negroid.

The Caucasian, or the White Race, brings up more difficult ques-

tions. Just as the Mongoloid and Negroid are diverse, so is the blue-eyed, flaxen, wavy-haired, ruddy and white complexioned Celt different in almost every particular. But the White Race, as it is often called, is taken to include a wide diversity of types, many of whom are not white at all. Thus, for example, Keane points out that the Black Berbers are Caucasic, and he goes so far as to class the Maoris of New Zealand, the Dyaks of Borneo and the Hawaiian Islanders under a branch of the White Race. With this, tho, present writers cannot agree.

There are certain points, however, even in this complicated matter that seem fairly clear. One is, that the further away from the center of the continent of Europe and Asia the observer goes, the more clearly do the evidences of a white race appear. Thus the nearest possible physical kinship is to be seen between a Celt and an Aino of Japan. Whatever doubt there may be about certain other savage races, there is little doubt with regard to these.

As A. H. Savage Landor has pointed out in his "Alone with the Hairy Ainu," they possess all the physical characteristics of the Caucasian. Living at the extreme eastern point of the continent, the Ainos are fair in complexion, rarely being as dark even as a southern Frenchman; the eyes have but little coloring pigment, being a light brown or gray, and are set straight in the head; the nose is finely shaped and slightly arched, and to American and European eyes many of them are quite handsome. Indeed, the older men would in many cases be indistinguishable from an elderly, well-bearded man in America or Europe. The hair is Caucasic in type. The race is by no means pure, and has suffered deterioration by being constantly pushed further and further to the edge of the continent, so that their only home now is on a few of the Japanese Islands. The traditions of the Ainos go back to a time when a large portion of the mainland was in their possession.

On the opposite point of the continent, in West Ireland, North Scotland and North Scandinavia, the same type appears, even more pure, for it has not been mixed with Mongol blood. There fair—and even red—hair is to be found, with blue eyes, orthognathous jaw, large cranial capacity and the various other marks distinctive of the Caucasic race. It would appear, therefore, that a white race had once lived in Europe and in Asia, which had been successively pushed further and further out by later peoples, the white strain being less adulterated the further it migrated from the pursuing foe, and keeping much of its purity only upon the very verge of habitable land on the continent. The Caucasic, therefore, is not so much the White Race as a true Caucasian who has made the White Race extinct, but in the doing so has incorporated with himself the various points of the

White Race, the mixture being more Archaean white on the edges and more Caucasian in the center.

A Caucasic-Archaean White Race, therefore, is definitely established, and is to be considered as a third branch of the human species, if it is constantly borne in mind that this is a race with a double origin and that many of the apparent discrepancies that occur in it are due to the varying proportions of admixtures to be found therein. The so-called Aryan invasion was truly an invasion in every sense of the word, but by a curious mental quirk the existence of the peoples who were invaded have dropped largely out of sight.

"A still more difficult question rises, however, when the conditions on the American continent are encountered. Keane declares that "owing to the absence of the higher apes," the New World cannot be regarded as an independent center of evolution for Man himself." The first part of the statement is true enough, but the conclusion is entirely without warranty, for no one would declare more certainly than Keane himself that Man is not descended from the higher apes. It has been shown that Man in an earlier period diverged from the mammalian stock, but it is not to be forgotten that he is a branch from the mammals, not a twig on a branch from the apes. The distinction is tremendous and vital. It is therefore no argument at all to endeavor to dispose of the origin of the paleolithic and neolithic American races by such a statement.

The archeological importance of America is greatly underestimated. Thus there are good grounds for accepting a Paleolithic Age in Patagonia; there are Neolithic remains widely scattered over the continent; there are irrigation projects in desert New Mexico, once a fertile and well-populated country, irrigation canals made before the lava flowed into them 3,000 years ago; there is a bronze age in Chimu, which was overthrown by the Nahoa invasion—bronze, moreover, of a proportionate alloy found nowhere else in the world; there are the whole group of Aztlan civilizations, of which the later Aztec, Toltec and Maya are still a riddle unread; there are the pueblo tribes, and the whole sealed book of the mound-builders and the makers of the beehive hut.

What is not the least strange of the ideas that have prevailed concerning the American continent and its population is that it must have come from Europe or from Asia. In order to try and bolster up the idea of the dependence of America on Europe for all she had, the old story of the "lost Atlantis" was revamped and an endeavor made to put the tale on a scientific basis. But the theory was never worthy of the support it gained, and it has now passed to the limbo of archaic beliefs together with the mandrake and the roc.

Scarcely less impossible was the idea that the primitive Americans

—that is, the American of paleolithic times—had crossed into this continent from Asia by way of Behring Straits. At first blush this seems a probable theory, but when the question of glaciation is taken into consideration and it is noted that the ice-cap extended far over the American continent and that the whole of the northeast of Asia and all the northwest of America was an absolutely impassable ice-barrier, the theory loses its appearance of probability. It is to be observed that this does not apply to recent immigrants, to the "North American Indians"—that is to say, the Hunting Tribes, whose nomadic wanderings extended so widely over the country; they bear no relation to the early settlers—who were not nomads.

Sir Daniel Wilson, an archeologist who has given much attention to American antiquities, declares upon this point: "The Western Hemisphere stands a world apart, with languages and customs essentially its own. To whatever source American man may be referred, his relation to the Old World races are sufficiently remote to preclude any theory of geographical distribution within the historic period." And again: "The studies of the monuments and prehistoric remains of the American continent seem to point conclusively to a native source for its civilization. From quipu to wampum, pictured grave post and buffalo robe to the most finished hieroglyphs of Copan and Palenque, continuous steps appear."

The absolute non-coincidence of American remains is the more remarkable when it is borne in mind that for so many years the endeavor was made to cause every find to be so interpreted as to bolster up the theory of European or Asian origin. Yet Daniel G. Brinton is even more emphatic. "I maintain therefore, in conclusion," he said in a paper read before the International Congress of Anthropology, "that up to the present time (1894) there has not been shown a single dialect, not an art or an institution, not a myth or a religious rite, not a domesticated plant or animal, not a tool, weapon, game or symbol in use in America at the time of the discovery which had been previously imported from Asia or from any other continent of the Old World."

Upon such a basis, then, it would seem the human species can be grouped into four races—the Negroid, the Mongoloid, the Caucasian and the Americ. The characteristics of the first three are very clearly seen, that of the fourth—if the Hunting Tribe be omitted—is very little known.

It may be objected that there is no sure evidence what was the racial division thousands of years ago. To this P. Topinard, in his "Anthropology," may answer. "Whether assisted or not by archeology," he says, "history narrates that, under the Twelfth Dynasty, about 2300 B.C., the Egyptians consisted of four races: (1) The 'Rot,' or

Egyptians, painted red and similar in feature to the peasants now living on the banks of the Nile; (2) the 'Namahu,' painted yellow, with the aquiline nose, corresponding to the population of Asia to the east of Egypt; (3) the 'Nahsu,' or prognathous negroes, with woolly hair; (4) the 'Tamahu,' whites, with blue eyes."

Thus, taking under consideration the Black Race first, as it is the most strongly differentiated, a possibly satisfactory division might be made much as follows:

Black	Negrillos	Bushmen
		Pigmies
	Negroes	Soudanese
		Senegambians
		Guineans
	Islanders	Negritos
		Papuans
		Australians
		Tasmanians
		Gonds

The Negrillo division of the Black Race includes those types of men which present dwarfish characteristics. Of these the two best-known examples are the South African Bushmen and the Pigmies. Both of these are of diminutive stature, the average height being under five feet, and certain stunted tribes showing an average of less than four and a half feet. The skin is very hard and much wrinkled; the nature is ferocious but without persistency; the birth rate is immense, a single child at birth being rare and triplets and quadruplets common; but the death rate is equally large, and longevity is absolutely unknown. They are dull black in color, the ear is small and ape-like, and the arms long.

The Negroes proper include those tribes which are found at their best in the upper reaches of the White Nile and about the Nyassas. In contradistinction to the dwarfish Negrillos, they are usually of large stature with a fair muscular frame. They extend from the fine race of the Gabooners in the north to the equally representative Zulus in the extreme south. The Nile tribes, true negroes, are of an intense glossy blackness in color, different entirely from the sootiness of the Negrillos, and unlike their dwarfish racial co-mates, they are inert and heavy in character, possessing little ferocity or cunning and susceptible of little improvement. The Senegambians, while possessing the essential traits of prognathism, thick lips, receding forehead, coarse but very white teeth and frizzled hair, are slightly less negroid in character; the ramifications of the branch are very

extensive, and they alone among the Black Races have given evidence of a possibility of progress. The Guineans comprised the tribes from which the slaves usually were drawn. They are more docile in character, less prognathous in jaw, and their color is less interpenetrative than that of the Nile tribes, but they are none the less distinctly a separate branch of the Black Race.

The Islanders is a loose term embracing a group of tribes, many quite divergent, which are spread over the islands of the South Seas. The Negritos—of whom the Andaman islanders are the best example—are in some measure a mixed race, but are unquestionably negroid. They disclose in especial excess the splay feet characteristic of the Black Race and the protruding heel. The Papuans are probably the root-stock of the two following subdivisions, the Tasmanians and the Australians, and they are a very distinctive type. Indeed, for many years they were classed as a separate race, but this position largely has been abandoned. They are by far the most intelligent of the Islanders and are distinguished very largely by their most characteristic hair, which, throughout all the branches of the division grows very abundantly and very long, possesses a curiously flattened structure and has a peculiarity of separating into tufts of great thickness and strength. The jaws are less prominent than those of the Negroes proper and the lips more shapely. The nose is notably unlike, being long and not too broad. The legs, long and thin, possess a distinct resemblance to those of the Negrillos, tho, of course, on a larger scale. The division of Gonds includes those aboriginal tribes of India whose presence there is so difficult of explication, but of whose racial characteristics as members of the Black Race there seems good evidence.

A consideration of the Yellow Race might lead to a general division as follows:

Yellow	Indo-Chinese	Thibetan
		Chinese
		Malay
	Tartar	Manchu
		Turk
		Samoyedes

The divisions of the Yellow Race are less confused. There are two main divisions, the Indo-Chinese and the Tartar, and between these two the difference is wide. The Yellow Race is characterized by long, straight black hair, which is nearly cylindrical in section, "by a nearly complete absence of beard and hair on the body, by a dark-colored skin, varying from a leather-like yellow to a deep brown or sometimes tending to red, and by prominent cheek-bones, generally accompanied by an oblique setting of the eyes."

Of these the Thibetans seem to represent a fairly pure stock, their isolation having contributed much thereto, and which renders them closely allied to certain of the Malay tribes of the Indo-Chinese group. The Malay is a widely spread branch and has proved one readily susceptible of change. Spreading from the most distant South Sea islands to Madagascar and Ceylon, it has left an imprint on the entire population of Oceanica which, by reason of its division into innumerable islands, had no opportunity to retain homogeneity.

The second great branch of the Indo-Chinese is the Chinese proper. It is greatly subdivided, but is strongly marked by racial as well as national characteristics. Subtended by the Malays and Thibetans, it has partaken of the natures of each of these, and provinces in China possess delimitations which have become extremely broad as the result of the density of the population and the scarcity of travel. The intrusion of Tartar blood of the Manchu line (the Manchu is now the reigning dynasty of China) has further complicated the condition of China, so that even the different strata of society in the same province will present problems of intermittent difficulty.

In addition to the Manchu division of the Tartar branch, there is a large group known as the Turks. These are the true dwellers of Turkestan, and there is a strong admixture of this blood in the Beloochis and other tribes on the northern side of the Himalayas; mixed to a certain extent (not great) with Aryan ancestral traits, they form the basic stock for the Turks of the Ottoman Empire. The Cossacks are true Tartars and seem closely allied to the Manchu, with a strong crossing of Turkish heritage. The third group is the Arctic or Samoyedic, a widely spread section of the Tartar race, including Lapps, Finns and in the most divergent example, the Eskimo.

The Yellow Race thus dominates the entire continent of Asia, except Hindostan and Arabia, and besides sweeps half way down through Oceanica. There, in the South Sea archipelagoes, it encounters the Islander branch of the Black Race, which in its turn has covered the entire continent of Africa south of the Saraha and its share of Oceanica. Such a partition, it is evident, is not only ethnological but also ethnographical.

Complex as the inter-tribal relations of the Black and Yellow Races have been, the intermingling of the White Races has been much greater, and consequently the differences between them more slight. In the classification of the White Race that is given below, the old Noachite terms have been used, because, as is well known, the distribution of the White Races does follow in a manner similar to the traditional wandering of the sons of Noah. It is still popularly held. This classification is as follows:

White	Hamitic	Berbers, Egyptians, Somali
	Semitic	Arabian, Abyssinian, Hebrew
	Japhetic	Celtic, Teutonic, Slavic, Italic, Iranian

The Hamitic nations now have fallen to a comparatively unimportant place among the White Races, but in the early days of civilization they were the leading peoples of the world. The Assyrians, the early Egyptians and the Phenicians were all Hamites. The Ionians of the time of Homer belong in the same group and had no small influence on the Hellenes of later dates, and the Etruscans were but little changed from the primal stock.

The Semitic grandeur also has largely disappeared. The Arabs, the Abyssinians and the Hebrews chiefly remain of this once powerful branch, which led all Oriental culture in its Chaldean power. The Elamites and the great conquerors of the Second Assyrian Empire were Semites, but perhaps what has always been the most distinguishing force of this line of the White Races has been its capacity for being absorbed into other peoples, and yet in its very process of absorption Semitizing the alien peoples themselves.

The Japhetic branch of the White Race is that which is dominant today. Where lines of divergence are as narrow as in the case of this branch of the human family, it avails best to make as clear a subdivision as possible by the old linguistic methods. Of such a basis five lines may be cited. Probably the purest and most primitive is the Celtic line, the earliest to diverge, and constantly driven westward, so that it is now confined to the interior and south of Ireland and parts of the west coast; the highlands of Scotland; the mountain fastnesses of Wales and the coasts of Brittany and Normandy, France, speaking the languages respectively of Erse, Gaelic, Welsh, Breton and Armorican. The true type seems to persist in a union of dark hair with light gray and blue eyes and a fair complexion (the flaxen-hair is an Archaean trait). The nature is impulsive, imaginative and chivalrous, but too individualistic to permit of national unity.

The Teutonic peoples are the antithesis of the Celts. Their language has had so formative an effect on all other language used by the

White Race, that its limits are vague and ill-defined. The old Maeso-Gothic, the foundation of the German language, was a Teutonic tongue, and high German to-day is the best example of the type. The impress is extremely strong on the English language and the composite Anglo-Saxon is in by far the largest proportion Teutonic. Where the Celt is imaginative the Teuton is solid; the Celtic impulsiveness is opposed by the Teutonic prudence, and wherever this phlegmatic race has abided, self-government and the arts of peace abound. The flaxen-haired, large-limbed Scandinavian is the extreme of the Teutonic type of physical frame, so far, at least, as can now be discerned.

The Italic group is of clear outline. It embraces the nations speaking languages generally known as the "Romance languages," and comprises the nations along the northern shores of the Mediterranean. The military régime of the Roman Empire, which was of Italic stock, wrought a profound effect upon the destinies of southern Europe and stamped its language indelibly upon the speech of Man. The assimilation by the later Romans of barbarian blood, weakened its permanence as a matter of physical differentiation. The character is passionate, vengeful and pleasure-loving, and by its readiness to consider only the things of the moment, capable of being directed to great deeds by capable leaders. The type is olive-skinned, with dark brown and black eyes and a very glossy hair.

The Slav sphere is of clear contour. The Russian since his first settlement has adopted a policy of exclusiveness to neighboring races and possesses no ability to colonize. His language and customs are strongly individualized and stereotyped and literature is scanty. Tho possessing abilities of a high order, the Slav is notable for a morbidness of temperament and a non-adaptability to progression which has isolated him from the world about him. A rigid class-demarcation, added to this immobility of conditions has led to stratified physical types, but in general it may be said that the Slav is well-built, regular-featured and possessed of an unusually luxuriant growth of hair.

Last comes the Iranian, probably the only branch of the parent stock to deviate from the general westward trend. The Iranians traveled southeasterly and passed over Persia into India. The great Oriental civilizations were theirs, the vast literature of Sanskrit is Iranian, and, moreover, the Iranian imprint upon southern Asia is that which has made it so entirely different in scope and mental attitude from the Asia north of the Himalayas.

On such debatable ground as the origin of races, statements must be cautiously made. Briefly, there are two schools, the one known as "polygenists" holding that the races of Man were evolved as a result of almost similar conditions in various parts of the globe, and that the causes of this variation are the differences of his origin and of his

environment. The other school, the monogenists, hold that Man was descended from a single pair of ancestors, or, it may be, a single group, and that all the variations of race have been brought about through environment alone. To this latter view may be added the hypothesis that Nature acts "per saltum," "by jumps," and getting tired of having yellow parents produce yellow children, she varied the program and arranged for one pair to be Negro. Anthropologists are almost evenly divided, tho perhaps the majority may be slightly in favor of monogeny. The present writer holds with the polygenistic school, for the reason that extensive migrations over glaciated areas in glacial times afford too many difficulties; but it is not desired to deal here with a subject calculated to provoke controversy.

The question always will be a difficult one, for the reason that the geological record is not perfect, and the paleontological record of man still less so. Just where the Man left the mammalian stem, and whether it was "per saltum," or through gradual process; whether it will be found that all races of Man approach more nearly to a persistent type in the anthropoid ape, or whether certain races of Man will be found more nearly allied to certain different varieties of fossil ape, are questions likely to be long of solution, for the answer may lie deep in some filled-up mountain valley, or in the bed of some marine or lacustrine basin.

CHAPTER V

PREHISTORIC ARCHEOLOGY

GREATER libraries than the world has ever dreamed of lie under foot, and scarce a fraction of the treasures of archeology have been exhumed from the strata wherein they lie. All know well the thrill of excitement which pulsates over a community—yes, over the whole world—when a discovery of gold is made, yet such is but a potential treasure for a few men, and is soon spent, while a "find" of true archeological worth is a treasure for all men and all ages to come.

Ruined palaces and fortresses, revealing tales more strange than any fairy story has yet given to the world, hide in the dense forests of Yucatan; cryptic puzzles, as yet unread, clamor for attention to all the world from the highway of Salisbury Plain, England; dim shadowings of the life of the Troglodyte come forth from the caverns of the Dordogne in France; while in every country are to be found the remains of Man side by side with the gigantic animals of an earlier time, bidding moderns seek them and reconstruct the wonders of that ancient age when the ancestors of the present races waged their wonderful war for life.

In every department of human thought the students thereof feel themselves to be working on the subject which is of the chiefest importance and of transcendent interest, but the archeologist affirms as reason for his plea that all these sciences, all these arts, belong to him, and that the groupings of Man and the development of Man along all lines are but superstructures upon the foundation he is laying. Neither is he confined to race, to period, or to type; if his taste runs to the small detail, he may spend his years deciphering the most minute, semi-obliterated inscription on a stone; or, if he so prefers, he may stand below cyclopean walls and tell the world who made them and how they were erected in their grandeur.

In its truest sense of the word, Prehistoric Archeology is comparatively a new science. For many thousand years men cared little for the history of any save their own country, and even until very recently all history taught in the schools began with Greece and Rome. But the reading of the hieroglyphic inscriptions of Egypt and of Babylon during the last fifty years forced upon the attention of thinking people the fact that history must be vastly more ancient, and to archeologists the wars between Athens and Sparta were combats of yesterday.

Linguistic difficulties next arose, and it was pointed out that many centuries must have elapsed before so complete a system as the hieroglyph and the cuneiform were seen to be could have evolved from primitive man. The gradual development of the arts likewise formed a puzzle to the historian, and the date of Man was pushed ever further and further back.

The evidences of organic descent changed the whole aspect of written history. Instead of considering Man as a unique creature, possessing a high degree of civilization, from which he afterward fell, it became clear that Man has risen. Only a slight knowledge of science was needed to show that the rise would increase in rapidity with later advances, and consequently would decrease in antiquity, so that the earliest faltering steps of Man in any direction must have been slow. This is a matter of historical progression solely and does not trespass on the disputed ground of spiritual advance.

When, therefore, the historian, looking back into the past, began to compare his earliest dates with the apparent dates of the first appearance of Man upon the Earth, he hastily broke company with a "historian of antiquities," and gave place to the modern prehistoric archeologist, who presents his science from the actual evidence of tangible objects themselves. Prehistoric anthropologists have investigated these objects and the various deposits containing them as to (1) their human origin, (2) the geologic age of the stratum in which they are found, (3) their original deposit in that stratum at the time it was formed (that is to say, an absence of intrusion or disturbance), (4) the association and superposition of the implements and objects in the stratified deposits; and by the knowledge and experience thus obtained they have determined that man made these objects, and, therefore, he existed in these localities in times of high antiquity.

Prehistoric Archeology deals with three periods, known respectively as the Paleolithic, the Neolithic, and the Bronze Age. They are each distinct from each other, altho the latter two show a certain amount of overlapping that is to be expected. But there is no evidence of a Neolithic race ever having gone back to Paleolithic methods, nor is there a case of a people which has learned to use metal that readily resumed the habitude of stone.

It is unquestionably true that the development of the various races that have been mentioned, the Negroid, the Mongoloid, the Caucasic and the Americ, followed slightly different channels at widely different speeds, so that the three ages will be found to synchronize in point of time with three peoples who may not be far distant from each other. Thus, it would be absurd to speak of the English at the Battle of Hastings—after such literary works as the "History of Alfred the Great"—as being Paleolithic or Neolithic Man, yet it is unquestionable that stone battleaxes were used against the Norman invaders.

The nature of the remains of Primitive Man were collated by Sir John Lubbock (Lord Avebury) in his "Prehistoric Times," when he said, "Archeology forms, in fact, the link between geology and history. It is true that in the case of other animals we can, from their bones and teeth, form a definite idea of their habits and mode of life, while in the present state of our knowledge the skeleton of a savage could not always be distinguished from that of a philosopher. But on the other hand, while other animals leave only teeth and bones behind them, the men of past ages are to be studied principally by their works: houses for the living, tombs for the dead, fortifications of defense, temples for worship, implements for use, and ornaments for decoration."

But it will immediately appear evident that all such investigation will depend very largely upon the location in which such finds are made; indeed, it will depend almost entirely upon such fact. When a flint scraper, however, is found in a river-drift or gravel-bed, which, so far as can be discovered, has never been disturbed, it may be taken as a fair assumption that the scraper and the gravel were laid down together. When, moreover, that same stratum contains a great number of such finds, the probability becomes stronger. When, yet again, those scrapers are found close beside the bones of some animal now extinct, but which lived upon the earth at the time that gravel bed was being laid down, the probability becomes assured; and when this juxtaposition is supported by similar finds in similar strata, probability becomes certainty.

Speaking broadly, the materials now available for the study of primitive man are threefold, "his implements, his monuments, and himself." The first, from which he rightly takes his name of Paleolithic Man, are in some respects the most important, as being immeasurably the most numerous and widespread, but chiefly because they often occur under conditions which afford the best proof of their artificers' extreme antiquity. The monuments, if such undesigned structures as shell-mounds or kitchen-middens may for convenience be so named, lie necessarily on the surface, or at most on raised beaches, while the fossil remains of man himself have been found almost exclusively amid the general contents, or at most under the stalagmite floors of his cave-dwellings.

If, then, the use of stone for implements was one of the most important lines of useful knowledge possessed by early Man, it becomes important to find out what was the stone so used and the reason for its selection. The two stones most commonly used were jade and flint, and these, accordingly, are found sometimes at long distances from any place where the unworked material could have been secured, showing either that there was some form of commerce in the earliest

times, or that the nomadic life of the Paleolithic Man caused him to traverse great distances.

It is remarkable how carefully the best kinds of stone were selected, even when very rare. Of this the most interesting example is afforded by the axes, etc., of Jade or Nephrite, of Jadeite and of Saussurite. These minerals are very distinct chemically, but so similar in appearance that they can only be distinguished by analysis. Objects made from them, tho far from common, are not very rare. Thousands of Jadeite implements and ornaments have been found in Central America, but no deposit has yet been discovered; and, indeed, the jadeite which has been used is of so uniform a texture and chemical composition that it seems as tho all of it had been quarried from the same bed.

Flint was the material most commonly used, but every kind of stone, hard and tough enough for the purpose, was used during the Stone Age in the manufacture of implements, some even harder, but few wherein the lines of cleavage were better adapted. Prehistoric Man valued flint on account of its hardness and mode of fracture, which is such that, with practice, a good sound block can be chipped into almost any form that may be required.

Paleolithic implements abound in the drift gravels; the surface is strewn with flint flakes and fragments of flint implements; and at the present time Grimes Graves is the only place in England where gun-flints are still made. For this purpose one particular layer of flint is found to be well adapted, on account of its hardness and fineness of grain; while another layer, less suitable for gun-flints, is known as "wall-stone," being much used for building purposes.

"It is interesting to find," says Sir John Lubbock, "that even in very early times the merit of the gun-flint layer were well known and appreciated; for altho there is abundance of flint on the surface, the ancient flint-men sank their shafts down past the layer of 'wall-stone,' which occurs at a depth of nineteen and one-half feet, to the gun-flint layer, which at the spot in question is thirty-nine feet deep."

In one case the roof of a passage had given way. On removing the chalk which had fallen in the end of the gallery came in view. The flint had been hollowed out in three places, and in front of two of these recesses pointing toward the half-excavated stone, were two deer-horn picks, lying just as they had been left, still coated with chalk dust, on which was in one place plainly visible the print of the workman's hand. The tools had evidently been left at the close of a day's work; during the night the gallery had fallen in, and they had never been recovered.

"It was a most impressive sight," says Greenwell, who made the discovery, "and one never to be forgotten, to look, after a lapse, it may

be, of 3,000 years, upon a piece of work unfinished, with the tools of the workmen still lying where they had been placed so many centuries ago."

The earliest manifestations of human art consisted of the chipping of implements of flint, practically the first known to have been made or used by man. They belong to the Paleolithic period of the Stone Age. This period has been divided according to progress in human culture, and divers names have been given thereto, following the taste of the writers or discoverers. M. Lartet named the epochs after the animals associated with the implements, and called them, respectively, the epochs of the Cave Bear, the Mammoth, and the Reindeer. M. Dupont, of Belgium, divided it into only two, and named the epochs after the Mammoth and the Reindeer. M. de Mortillet has divided it into five epochs, and has named them, respectively, the Chelléen, after the station of Chelles, a few miles east of Paris; the Acheuléen, after St. Acheul on the river Somme; the Mousterien, after the caverns of Moustier on the river Vézère, Dordogne; the Solutréen, after the rock shelter of Solutré near Macon; and the Madelainien, after the rock shelter of La Madelaine, Dordogne.

The peculiar characteristic of the implements of the Paleolithic period is that man's cutting implements, usually of stone, preferably flint, were made by chipping. In the later epochs of the Paleolithic period certain implements were made of bone and horn, which were ground or smoothed, while those of stone were not. It is not, however, to be supposed that every chipped stone implement belonged to the Paleolithic period, for the prehistoric man of the Neolithic period chipped many implements of stone. Yet E. B. Tylor, in his "Anahuac," points out that force was probably also used and describes a process he saw in operation on flakes of obsidian.

The flint implements of the Chelléen period are, as is to be expected, extremely rough. Oval in shape, they possess a distinct cutting edge at the point, and the general shape was that of a plum stone, a few being of a sharper curve like an almond. It is not to be supposed that these were determined differences, but rather were dependent upon the nature of the original fracture.

But implements of this character are found widely spread, altho—and this is worthy of profound attention—they are not found in northern countries which were under the ice-cap. In the United States, while it cannot be stated that their nature is such as to demand precisely the same conclusions that have been reached in Europe, yet Thomas Wilson, in his "Prehistoric Art," seems justified in saying: "It is apparent on slight inspection that these implements found in the United States, altho mostly on the surface, are of the same Paleolithic type as those found in the gravels of Europe and elsewhere."

The Cavern Period, as following upon the Drift, shows a distinct advance. "It appears certain," says Wilson, "that there was at the beginning of this epoch a material change in human art and industry. The Chelléen and St. Acheuléen implements, so widespread, were superseded by objects now found in the caves and rock shelters occupied by man. This statement might be doubted if it rested on a few objects, but its truth will be apparent when we consider that these implements have been found throughout western Europe by hundreds of seekers, in thousands of places, and to the number of tens of thousands, but 'never associated' with 'cave implements' or objects; while on the other hand, tens of thousands of cavern implements and objects have been found in their appropriate places and never associated 'with Chelléen or St. Acheuléen implements.' I say 'never'—if any have been thus found, the proportion is insignificant, not one in a hundred, so that the statement is substantially true."

The art of flint chipping has never, in prehistoric times, nor among prehistoric or savage peoples, attained a higher degree of excellence than during the Solutréen epoch. There seems to have been an evolution from the rude and heavy Chelléen implements up to the fine Solutréen leaf-shaped blades. What time elapsed between the two there is no means of determining; it is to be counted by geologic epochs, and not by years or centuries. There was a regular and steady improvement in the art of flint chipping, produced, apparently, by continued experiment and practice, the result of which must have been communicated or transmitted from father to son, from teacher to student, from master to apprentice, until the ideal flint chipping was attained in the Solutréen leaf-shaped blades.

From chipped stone to polished stone does not seem so great a change, yet between the paleolithic and the neolithic period is a wide, unbridged gap. The wild, hairy savage of Paleolithic times, with a marked difference even in shape of skull, was a man with an ideal, with a sense of beauty, with a desire not only to make those things which he knew he needed, but even to decorate them. From the rude flint flake to the carving on the reindeer horn (to be dealt with in Prehistoric Art) is a long step, yet this step paleolithic man took, and his progress can be traced along every inch of the way.

But Neolithic Man was a widely different being. True, he followed the use of the flint implement, but he carried it to a higher perfection. He adopted a local habitation and a permanent place of residence, he became an agriculturist as well as a hunter and fisher, and he buried his dead as though expectant of a life to come. He built houses and erected wonderful megalithic monuments, and at the last discovered the art of smelting metals, and with Bronze weapons and ornaments ushered in the Age of Iron.

The great characterization of the Neolithic period is the wonderful

change in ornamentation, the drawings of the later paleolithic period giving place to mere geometrical designs, and the polishing of the flints after they had been chipped, and the greater skill and marked care shown.

After the flint flakes, used for many purposes, principally as knives, perhaps the next in importance are the axes or celts. There are many forms of these celts and these flakes, which have been called chisels, scrapers, axes, adzes, and so forth, but the next true departure is the spear-head.

These spear-heads are often of great delicacy of make, so fine, indeed, that they have not been duplicated by any modern attempts. The larger scrapers can be easily made, but the manual dexterity required for the making of a long, thin, evenly beveled spear-head, and the time and patience demanded, are not to be found to-day. As has been wisely said, let any one who does not appreciate the value of these flint implements in determining the location of Man try to make one of them, and he will find it to be a task of considerable difficulty.

Of even more interest are the megalithic monuments of prehistoric man. In every country that has been in any sense investigated, the remnants of strange constructions of prehistoric times remain. Whether it be the circle at Stonehenge, or the mounds of Ohio, whether it be the monuments in the desert near Mount Sinai or the huge stones of Peru, whether it be the pyramids of Mexico or of Egypt, the dolmens of Scotland or the menhirs of Ireland, everywhere they are encountered.

England is full of them and the riches of the American prehistoric period are only barely touched. "In our own island," says Sir John Lubbock, "the smaller tumuli may be seen on every down; in the Orkneys alone it is estimated that 2,000 still remain. On the Wiltshire Downs there are over 1,000, in France there are 4,000 dolmens, 1,600 menhirs, and 450 stone circles; in Denmark they are even more abundant; they are found all over Europe, from the shores of the Atlantic to the Ural Mountains; in Asia they are scattered over the great steppes from the borders of Russia to the Pacific Ocean, and from the plains of Siberia to those of Hindostan; the entire plain of Jelalabad being literally covered with tumuli and monuments. In America we are told that they are numbered by thousands and tens of thousands; nor are they wanting in Africa."

The stone circle is usually a ring of upright stone surrounding a mound. Often, however, it is on a level piece of ground and has an avenue of menhirs leading up to it. The most famous of them all is Stonehenge in England. There were thirty rudely hewn pillars from four to eight feet wide, two to four feet thick, and sixteen feet high above the ground, and about three or four feet apart, forming

a circle a hundred feet in diameter. Each of these pillars had on its top two tenons which rested in mortice holes cut in a stone architrave connecting each pair of pillars. Most of the posts and architraves have fallen to the ground, but enough remain to show clearly the size and pattern of the structure. An inner circle of stones had ten posts in five pairs, each pair being about ten feet from the one on either side. The material of these posts and architraves is sandstone found in the vicinity; but inside of the second circle there is a third small circle with posts of a blue igneous rock, which is supposed to have been brought from Ireland. The largest of these is seven feet long, two feet wide and a foot thick. A large flat stone in the center of the circle is supposed to have served as an altar.

It is an inexpressible pity that one of the finest megalithic monuments in the world should have been despoiled. Of the great temple at Avebury, in Wiltshire, England, it has been said by one of its admirers that "it did as much exceed Stonehenge, as a cathedral a parish church." Once 650 great stones, forming a vast circle around an artificial hill, and led up to by two avenues of menhirs half a mile long, stood upon the plain, but the little village of Avebury has been built upon and of the hill, the great megaliths have been broken up for building stone, and of the great ruin, only twenty stones are still standing.

Great as are the works of prehistoric man in Britannia, Gaul and Mauritania, they are rivaled by those of prehistoric man in the New World. "South of the barbaric mound-builders of the Mississippi basin," says A. H. Keane in his "Ethnology," "follow in almost unbroken succession the Casas Grandes of the Pueblo Indians, New Mexico and Arizona; the truncated pyramids and other remains of the Toltecs and their Nahua successors on the Anahuac Tableland; the palace of Mitla, South Mexico, of classic beauty; the elaborately ornamented temples, palaces, convents, raised by the Mayas of Palenque, Uxmal, Chichen-Itza and other cities of Yucatan; the great temples of the sun, the causeways, aqueducts and terraced slopes of the Peruvian Quichuas. Some of these are prehistoric, while others reach well into the historic period. But none can compare in magnitude and exquisite finish with the stupendous megalithic edifices of doubtful origin, which stand in an almost uninhabitable region near the southern shores of Lake Titicaca on the Bolivian plateau, nearly 13,000 feet above sea-level.

Altho often visited and partly described, full justice has only quite recently been done to these astounding ruins of Tiahuanaco by Stübel and Uhle, who have devoted a sumptuous volume to their description and illustration. The monuments, which cover a large area between the lake and Pumapunga, tho chiefly centered about the Ak-Kapana hill, here shown to be a natural formation, not an artificial

mound, are of an absolutely unique character, despite certain general resemblances to the neolithic structures of the eastern hemisphere. As shown by the numerous highly polished slabs and blocks lying flat on the ground, as if ready for the mason, it is evident that all formed part of a general design on a scale rivaling that of the largest Egyptian temples, but never completed, the works having apparently been interrupted by the Inca conquerors. They must have been in progress for some generations before that time, for the blocks, some weighing from 100 to 150 tones, had been conveyed with primitive appliances from distances of many miles over rugged ground, up steep inclines, and in some cases across several inlets of Lake Titicaca.

It is notable that certain of the stones, like those of Stonehenge, have shoulders for the reception of horizontal connecting beams, but far better dressed and mortised. Others form doorways hewn in a single piece, one of which at Ak-Kapana is the crowning triumph of the primitive American architecture. This marvelous monolith, weighing over twelve tons, is richly carved on one face with symbolic devices and the image of Viracocha, tutelar deity of the Bolivian Aymaras, overthrown by the Quichua worshipers of the rival Peruvian sun-god. Nor can mention be omitted of the stupendous earthworks of the Mound-Builders, whose very origin is so obscure. Widespread as are megalithic monuments in the Old World, these mounds are even more numerous in the New. The number of them catalogued runs into hundreds of thousands, and they are found as forts, as temples, as observation points; in the forms of animals, birds and human figures; of regular geometrical forms and of shapes the very purpose of which is unknown; of several different styles of construction, presuming the existence of an extensive civilization over the entire United States.

"Lacustrine or marine settlements form an interesting feature in the evolution of human progress," points out A. H. Keane in his "Ethnology," "their development being intimately dependent on the local conditions at certain stages of culture. Communities seated by the shores of lakes or shallow inland seas possess obvious advantages over tribes confined to the woodlands or the plains. They draw their supplies both from land and water, and to their other resources are added navigation followed by barter and piracy. But on the other hand, the wealth thus rapidly accumulated exposes them to the attacks of predatory hordes, to guard against which they take refuge in their boats. They are thus gradually transformed to a floating population, which soon learns to adapt itself to the new environment by erecting dwellings on platforms resting on piles driven into the mud or sands of a shelving beach. Then, when peaceful days and orderly government take the place of lawless habits, a return is made

to terra firma, and the abandoned lacustrine dwellings soon disappear; but the sites remain the safe depositories of the multifarious objects of human industry which have accumulated beneath the shallow waters during their occupation."

Such is the history, either completed or still in progress, of the numerous floating habitations which are found in every part of the world from the New Guinea coastlands and the estuaries of the Borneo rivers to Helvetia and the British Isles, and beyond the Atlantic to the aquatic settlements of the Maracaibo Sea, to which the surrounding region owes its present name of Venezuela, "Little Venice." Such especially is the history of the Swiss lake-dwellings, the recent exploration of which has shown them to be one of the richest storehouses of neolithic and prehistoric industries. Antiquaries have already explored over two hundred of such stations, some of which were occupied again and again, like Hissarlik (Troy), Lachish, and those other eastern cities, where the vestiges of several distinct civilizations are found superimposed one on the other.

At Robenhausen, south side of Lake Pfäffikon, three such prehistoric occupations have been disclosed, each destroyed before the next began, as shown by the three sets of piles (100,000 altogether), each projecting from 3 to 5 feet higher than the one below. So also at Morges, on the north side of Lake Geneva, there were three different stations, here, however, not superimposed, but standing in close proximity within a space of about a third of a mile. Nevertheless, they were not inhabited simultaneously, but successively, as shown by their relics, all stone in the earliest, stone and rude bronze hatchets in the next, bronze alone and very fine bronze in the last, the great prehistoric city of Morges. Even the present Morges appears to be some 1,200 or 1,500 years old; yet it never had any record or memory of its predecessor till its existence was revealed in 1854 by the subsidence of the lake, due to an exceptionally long drought.

The Bronze Age is one of the most unsettled periods in Archeology. It is clear, of course, that it follows the Neolithic Age in general and that it preceded the Age of Iron, but it by no means is clear that it was not in many cases synchronous with the later Neolithic. Every find of bronze as weapons and implements has been made in connection with Neolithic remains and there is no instance of a long continuance of the use of bronze after the knowledge of iron. But the use of bronze as ornamental purposes continued well on into historic times, and indeed it cannot be said to be entirely abolished to-day.

"Many objects of wrought copper have been found in America," says Thos. Wilson. "The Lake Superior copper mines in the States of Wisconsin and Michigan appear to have been the center of manufacture, from which the distribution took place, and thence the manufactured implements spread, in gradually decreasing numbers, in every

direction throughout the present territory of the eastern United States. The modes of treating copper, whether by smelting, melting, casting or hammering, and if any or all of these, what amount of heating or melting was done, has never been fully investigated nor have they been satisfactorily determined. Some of the objects were certainly of virgin copper hammered cold, and they were thus made into bracelets, rings, and similar objects of personal adornment, and also into axes, knives, and spearheads. These copper weapons and ornaments continued to be used contemporaneously with cutting implements of stone and of ornaments of shell and bone.

"Among the many mysteries of prehistoric archeology growing out of mound excavation in the United States, wherein things strange and wonderful but of undoubted genuineness and antiquity are found, none are more unexplained than the thin sheets of copper wrought by repoussé work into curious and unknown devices found in mounds and earthworks in widely separated regions of the country. The principal specimens come from the Tumlin mounds on the Etowah River, near Cartersville, Ga., but Ohio and Illinois mounds also have furnished examples."

By such steps as these, therefore, can be roughly traced the development of Man from his earliest ancestor as Man down to the Historic period. How many years elapsed between the period of "Homo Primigenius" and the first flint-flake there is no means of determining, neither can it be said whether it was in hundreds, thousands or tens of thousands of years. It is now thought improbable, however, that Man's ancestor in the Tertiary Epoch could rightly be called Man, but it is obvious that the date of the beginning of the Quaternary would be extremely difficult to estimate, even approximately.

His life was largely influenced by his weapons and his tools, and they again reflect to his successor the life he led. By their means, therefore, it becomes possible in a measure to reconstruct the life of Primitive Man and to shadow forth the development of that more subtle force called culture. Anthropology has detailed what Man is and the conditions of his physical frame, Ethnology has set forth his racial division and specific unity, Ethnography has pointed out his distribution, and Archeology has collated and classified the evidences of his early being; it remains therefore to bring all these together under a consideration of the development of culture, that perhaps a vague outline of the philosophy of primeval history may come into view.

CHAPTER VI

THE DEVELOPMENT OF CULTURE

To THE development of Man as an individual and as a race must be added his advance as a producer of that which is called Civilization. For it is the especial prerogative of Man to be the ruler of his environment, not the slave of it, and whereas the effect of the animal upon the environment is always purely unconscious, the influence of Man is purposeful. He is not content with taking Nature as he finds her, but has the audacity and the power to utilize her forces and even to divert them.

It is of course abundantly clear that such a daring flight of thought never occurred as such to Primitive Man, nay rather, that he conceived Nature as being a supernatural or a group of supernaturals; but none the less, even at such time, he conceived the idea of influencing those supernatural personified forces by worship, sacrifice and so forth. It is one of the essential characteristics of Man that he is conscious of his power and seems inwardly to believe with the Ancient Pistol, "The world is mine oyster, which I with mine sword will open."

That the human embryo passes through the various stages of the mammalian stem prior to the branching forth of Man has been abundantly shown, and indeed now is not to be questioned, and it is equally true that the development of the mind of the child during childhood follows closely upon the scale of mental faculties possessed by the lower animals, paralleling them in nearly all details. The emotional faculties of the child, moreover, can scarcely be distinguished from those belonging to the simpler orders of animal life.

If the history of the individual be used as a comparison for the history of Mankind, precisely the same condition will be seen to appear. In the earliest times of Man his mental condition was not different from that of the creatures around him, but he possessed the capacity for greater progress and higher advancement than they. The very flint instruments that have been considered tell the same story, passing from the rudest flakes of the Chelleen division of the Paleolithic period to the most polished specimens of the Neolithic Age just ere bronze changed the conditions of Man and led to the way to a further civilization. Likewise in shelters, from the rude sticks

covered with the skins of animals and heaps of rough piled stones to the wonders of the Parthenon is not one mighty stride born from an inspiration, but a long, slow, careful process, each improvement building upon the last. And whether such a comparison be carried out into the mind of thought, from fetichism to the Brahma of the Vedas and the God of Isaiah, from guttural stammerings to the oratory of Demosthenes and the literature of Goethe, from the use of the wife as a beast of burden to the modern railroad, all alike tell the same story of progress starting from the humblest beginnings, the same triumphal march of evolution.

It seems wise to point out at this place that the Development of Culture is not to be regarded as the steps that have been taken from imperfection to perfection, but as the advance from imperfection to a slightly less imperfection. The human mind at present is not formed, but only forming, and there are heights illimitable yet to be climbed. By slow and dubious steps, groping wearily in the dark, the ancestors whose lives are learned only from their flint remains, climbed to simple consciousness. Self-consciousness—a far higher concept—was not reached probably for thousands of years later, and unconscious self-consciousness, paradox tho it seem, is one of the avenues along which it is seen that the mind of Man is tending.

But it would be a heinous mistake to suppose that "surely we are the people and wisdom will die with us," for it is as affirmed as any scientific fact can be that Evolution is an invincible force not to be stopped by any human agency. It has always gone on, it still is going on, and so far as can presently be seen, it always will go on. Some of the old mental faculties are dying out and others taking their place, not with any degree of uniformity, but in such wise that looking back over a vista of centuries it can be seen that there has been a distinct advance. There have been losses also, but the general direction has been upward. Whether the present gropings for relations to a supersensual sphere, such as telepathy and clairvoyance, are vague shadowings of future lines of development or merely temporary phases of thought is yet to be seen, but it is certain that they cannot be overlooked in any consideration of the probable development of the future.

A long distance has been traversed, how great a distance is best seen by comparing the percept of the savage and probably of primitive man with the concept of the best developed mind. Suppose the word star is a simple idea or percept, the recognition of a number of stars, or of bright, twinkling objects resembling the shining of stars, is a complex idea or recept So far the mind of the higher brutes keeps pace with the developing mind of man. But the next step carries us beyond the mental powers both of infants and of animals; neither can conceive the idea of a star as present to the mind of an astronomer. This is an abstract idea or concept, and is unattainable except through

the medium of articulate language. Where the child sees a twinkling spark the astronomer is conscious of a flaming sun; where, until lately, men recognized the symbol of unchangeableness, the astronomer knows he beholds stupendous worlds rushing through space at unimaginable speed; where the Hebrew seer beheld "lesser lights" stuck in a solid firmament solely for the service of man, the astronomer knows that his eye beholds objects at a distance of millions upon millions of miles, objects whose grandeur throws our whole solar system into insignificance. An abstract idea is itself capable of containing a volume of knowledge; its capacities have hardly any limits but that of the mind itself.

Thus upon the character of the traditional material lies the chief line of difference in the results of thought. Herein lies the immense importance of folklore. Herein also lies particularly the enormous influence of current philosophic opinion upon the masses of the people, and herein lies the influence of the dominant scientific theory upon the character of scientific work. It would be in vain to try to understand the development of modern science without an intelligent understanding of modern philosophy; it would be in vain to try to understand the history of medieval science without an intelligent knowledge of medieval theology; and so it is in vain to try to understand primitive science without an intelligent knowledge of primitive mythology. Mythology, theology and philosophy are different terms for the same influences which shape the current of human thought and which determine the character of the attempts of man to explain the phenomena of Nature.

The influence of traditional material upon the life of man is not restricted to his thoughts, but manifests itself no less in his activities. The comparison between civilized man and primitive man in this respect is even more instructive than in the preceding case. A comparison between the modes of life of different nations, and particularly of civilized man and of primitive man, makes it clear that an enormous number of actions are determined entirely by traditional associations.

"When we consider," said John Evans before the Anthropological Society of England, "for instance, the whole range of our daily life, we notice how strictly we are dependent upon tradition that cannot be accounted for by any logical reasoning. We eat our three meals every day, and feel unhappy if we have to forego one of them. There is no physiological reason which demands three meals a day, and we find that many people are satisfied with two meals, while others enjoy four or even more. The range of animals and plants which we utilize for food is limited, and we have a decided aversion against eating dogs, or horses, or cats. There is certainly no objective reason for such

aversion, since a great many people consider dogs and horses as dainties.

"When we consider fashions, the same becomes still more apparent. To appear in the fashions of our forefathers of two centuries ago would be entirely out of the question and would expose one to ridicule. The whole range of actions that are considered as proper and improper cannot be explained by any logical reason, but are almost all entirely due to custom; that is to say, they are purely traditional. This is even true of customs which excite strong emotions, as for instance, those produced by infractions of modesty."

It will be obvious to the reader that the modern viewpoint of Culture is that it has developed, not that it is the remains of something still higher which has been gradually lost. The curious theology of the Dark Ages, which had a faculty for mystery and very little for facts, tried to force upon everybody the doctrine which depicted Adam and Eve as possessing all knowledge, and their descendants as continually falling away therefrom. Even in the nineteenth century, in his "Soirees de St. Petersburg," Count Joseph de Maistre wrote: "We separate ourselves always from that banal hypothesis that Man had gradually elevated himself from a condition of barbarism to an understanding of science and to civilization. This is the fondest dream, the mother-error, and as it is taught in the schools, the underlying falsity of our age." He goes on to speak of the "philosophers of this unhappy age, who, with the horrible perversity that we have seen persist in their errors in spite of the warning they have received." This is almost the last statement of its kind in the degeneration theory.

But progression in culture, while universally conceded at the present time, is by no means a new idea. Even the historian Gibbon, in his "Decline and Fall of the Roman Empire," perceived that by no other conception save that of progression could the events of history be read intelligently. "The discoveries of ancient and modern navigators," he said, "and the domestic history of tradition of the most enlightened nations, represent the human savage naked both in mind and body, and destitute of laws, of arts, of ideas and almost of language. From this abject condition, perhaps the primitive and universal state of Man, he has gradually arisen to command the animals, to fertilize the earth, to traverse the ocean and to measure the heavens. His progress in the improvement and exercise of his mental and corporeal faculties has been irregular and various. Infinitely slow in the beginning and increasing by degrees with redoubled velocity, ages of laborious ascent have been followed by a moment of rapid downfall; and the several climates of the globe have felt the vicissitudes of light and darkness.

"Yet the experience of four thousand years should enlarge our

hopes and diminish our apprehensions; we cannot determine to what height the human species may aspire in its advance toward perfection; but it may safely be presumed that no people, unless the face of nature is changed, will relapse into its original barbarism. We may therefore acquiesce in the pleasing conclusion, that every age of the world has been increased, and still increases, the real wealth, the happiness, the knowledge, and perhaps the virtue of the human race."

That two such diverse points of view should have had many wise supporters leads to the conclusion that there must be something that is true in each. "Of course," says E. B. Tylor in his "Primitive Culture," "the progression theory recognizes degradation, and the degradation theory recognizes progression as powerful influences in the course of Culture. Under proper limitations the principles of both theories are comformable to historical knowledge, which shows us, on the one hand, that the state of the higher nations was reached by progression from a lower state, and, on the other hand, that culture gained by progression may be lost by degradation. If in this inquiry we should be obliged to end in the dark, at any rate we need not begin there."

The famous argument adduced by Niebuhr against the progressionists that "no single example can be brought forward of an actually savage people having independently become civilized," seems to possess a great deal of strength until it is pointed out that the obverse of the same question may well be put to the degradationists, in the following form: No single example can be brought forward of an actually civilized people having independently become savage. There are things which lend themselves "prima facie" to support, and others that do not, and the idea, for instance that a tribe which had learned the production of fire by a drill should willingly go back to the more toilsome method of rubbing two sticks together belongs to the latter class.

But Sir Charles Lyell, with the vein of sarcasm he knew so well to use—sometimes disastrously—deals with the degradation theory in such wise as to settle it in a few sentences. Speaking of the progressive nature of the finds in earlier geological deposits, and contrasting the actual evidence with the imagined hypothesis, he says, "Instead of the rudest pottery or flint tools, so irregular in form as to cause the unpracticed eye to doubt whether they afford unmistakable evidence of design, should we not be finding sculptured forms surpassing in beauty the masterpieces of Phidias or Praxiteles; lines of buried railway and electric telegraphs, from which the best engineers of our day might gain invaluable hints; astronomical instruments and microscopes of more advanced construction than any known in Europe, and other indications of perfection in the arts and sciences, such as the nineteenth century has not yet witnessed? Still

farther would the triumphs of inventive genius be found to have been carried, when the later deposits, now assigned to the ages of bronze and iron, were formed. Vainly should we be straining our imagination to guess the possible uses and meanings of such relics—machines, perhaps for navigating the air or exploring the depths of the ocean, or for calculating arithmetical problems beyond the wants or even the conceptions of living mathematicians."

It may be assumed as proved, therefore, that Culture is to be regarded as a matter of development, rather than as a matter of deterioration, and that all the study of Prehistoric and of Historic Man is to be regarded as an appanage of a study of Culture. In a preface to a work, "History of the Mental Growth of Mankind in Ancient Times," John S. Hittell has propounded a series of questions, the answers to which would cover the whole history of the development of Culture. It is most suggestive, if only to show the immensity of the field the student of Culture must endeavor to cover.

When the question arises as to the divisions in the development of culture, Hittell makes a triple culture step, Savagism, Barbarism and Civilization. The division is arbitrary, of course, and the nations that he places in each division will not secure general agreement, and it would seem perhaps more convenient to add a fourth, splitting in twain his division of Barbarism. In the division of Savagism can certainly be placed the entire Negroid Race, for it cannot be said that any single tribe of the black race—and this is a sufficiently remarkable fact—have ever reached Barbarism, much less Civilization, Uncultured they have been ever, and it appears probable that ignorant they will ever remain. Hybrids of negro and white may continue and flourish, nurtured under a non-indigenous hothouse condition of civilization they may prosper, but the Black Republic and the Negro Empire of Haiti answer all questions as to the fate of negroes, after they have been taught, being left to their own devices. The Negroid, living in Negroid environment, so far as can be found out, has made no step toward true civilization.

There is probably some little arrogance in making a distinction between types of Civilization and making a separate class of them, but none the less a word is needed to express the races which advanced to a certain point, and then, for many reasons, suffered an arrest of development. The Chinese, for example, cannot be called a barbarous race, as Hittell has done, for their civilization is equally well grounded with the Caucasian. But it has not reached as far, and it does not seem to be progressing, insomuch that they are always cited as an example of arrested development. Of a far lower order are the Nahua and Aztlan civilizations in America. It might be well, therefore, to class such nations as the Chinese under "Arrested Civilizations" as contrasted with "Progressive Civilizations," it being

understood that no stigma attaches thereto. The Archæan White race also would come under this class.

Barbarism is certainly the condition of the primitive American races. They had only recently arisen from the stone age, and despite the wonderful works that they had succeeded in doing, their only tools were of bronze. It is laying a little too much stress on bronze, perhaps, to make this the cause for a culture-division, but in the case of the American Primitive Races, this was coupled to customs purely barbaric, such as human sacrifices and cannibalism.

For example, it is stated that "the most common method of sacrifice among the Aztecs was that the person was laid with his back upon a convex stone, and while his legs, arms and head were held by five priests, another cut open his breast, and took out his heart, held it up to the sun, rubbed the lips of the idol with it and then threw it into a basin which stood on the altar. If the victim was a prisoner of war, the corpse was thrown from the top of the temple pyramid, where it was picked up by the owner, the captor, who took it to his house to be cooked and eaten. When the maize began to sprout a boy and girl of noble blood were drowned; when it began to blossom, four children were starved to death in a cavern." Another custom was that of starting the new fire each temple year upon the naked breast of a slave.

Such a division would give Savagism, including the Negroid Race; Barbarism, comprising the Americ Race; Arrested Civilization, the Mongoloid and Archaean White; and Progressive Civilization, the Caucasic.

The fourth division of mankind, that of "Progressive Civilization," truly seems to be the heritage of the Caucasian race, the home of the various branches of which, having absorbed aboriginal inhabitants, extends from Ceylon to Scandinavia, and in whose grasp North America and Australia have fallen. It would be taken to include the Greeks, Romans and the European nations generally. Whether the effect of the Caucasian influence upon the arrested development of the Mongoloid (as in Japan) will evoke a new growth in that division of the race is not improbable, and if so, would only serve to show that Mongoloid civilization culture is true progressive civilization, temporarily arrested but only slumbering.

American civilization is not less deserving of study than those of earlier times and lower rank. Its startling rise and its supremacy in the one aspect of industrial adaptability are characters of the most profound interest. The causes that have operated within three centuries to bring together the nuclei in Virginia, Maryland, in New Amsterdam and in New England, to add to these elements the most diverse possible, and therefrom to educe a civilization with a national

ideal different from any of those that have gone before, is a matter for very careful study.

It would almost seem as though the culture of the United States was not so much slightly changing the old channels, as cutting new ones. The occultism and mystery of the east is hetero-mundane to the purely scientific attitude of the ideal European mind; but the endeavor on the part of the American to transliterate pure into allied Science and intellectualism into utilitarianism is again more different still. It is not difference of degree, but a difference of kind, and those who are heedfully observing the culture-development of America are beginning to see that the New World will, when she reaches a full strength, give to Man a Culture different from any that has gone before.

That this is not realized perhaps is due to the fact that the prophets of that spirit have not yet appeared; that the poets, artists, architects, sculptors, dramatists and scholars, are still in the lotos-dream of European ascendency. The engineer, the mechanician, the inventor, the industrial monarch, the railroad king, and the Great Khan of trade, are more in keeping with the growing American spirit, and hence arises the anomaly of those men's names being upon people's lips who seem to have naught else but wealth to recommend them as the cause of fame.

It will appear in course of time, however, that the public sense is none so trifling a thing, and that these men stand for an ideal yet barely grasped at, hardly felt, wherein ultilitarianism will arise into a mighty force, and the spirit that shall move men's souls will be that of prizing usefulness to their fellowmen more than their favor. To desire to grow rich for the sake of selfish luxury is an ignoble seeking, and it seems unjust to American culture to suppose that this is the cause of the money-making spirit; it would seem juster and not a whit less true to believe that the strife for the acquisition of wealth is due to an inherent sense that the masters of the world in the future will be Americans and that the resources of the world should be under their hands.

The old Chaldean culture lent a magic spell over the mind of Man, yet made him conscious of his Destiny; the Grecian culture founded itself upon estheticism, but taught him Beauty; the Roman culture was built up by the sword, yet Justice and Law became its heritage; Latin Christianity called in the aid of superstition, yet from it Man learned Reverence; northern Christianity, was constantly riven asunder in theological bickerings, yet did the race learn Religious Liberty; France passed through the scenes of the Terror, to teach the Kinship of Classes; England was forced to never-ceasing vigilance in the waters around her island home, that Dignity and the

power of National Protection might be made known; and America, amid her throes and struggles, stands as the Good Samaritan to the world's wretched ones, tending them, guarding them, teaching them to be worthy of the land of their adoption. America is yet a child, but men are beginning to see that her ideals are not borrowed and that her Culture is her own.

CHEMISTRY

INTRODUCTION

Technically it is difficult, almost impossible, to draw sharp distinctions between the various subdivisions of natural science. Omitting consideration of mathematics, which constitutes a necessary, and convenient mode of numbering, diagrammatization and quantitative interpretation of natural as well as of other phenomena—a clear and concise language—the fundamental sciences are physics and chemistry. Within the last half century the borderland of these two has become so elastic in its boundaries, that there has developed again an original science so closely involving the characteristics of the two fundamental ones that it is called physical chemistry. With a clear understanding of the foregoing there should be no misinterpretation of what follows in this "Introduction" or failure to appreciate what has been set forth within the covers of this book by its author.

Chemistry took its origin out of knowledge of small mysteries. Even to-day many may reasonably look with wonder at the accomplishments of the chemist, who seems to be a master at massive as well as at diminutive legerdemain. Unfortunately, at times it is assumed that he knows more than he does, and some, as in the charlatan days, pretend to be wiser than they are. The history of chemistry for the past two centuries has been the history of the progress of civilization. Its careful student will draw from it values that are cultural, material and moral.

Its educational value depends upon the accuracy it gives one's powers of observation, training in the correlation of the facts observed, tracing the underlying laws thus brought out, and the stimulation of the imagination to bring other facts, apparently not in conformity with the laws, into harmony with them or to so alter the explanations secured as to include the seeming exceptions. Thus theories, propounded as a logical sequence, which, as Shenstone has said, are as "searchlights which cast light into dark places and enable us to see, sometimes plainly, sometimes only dim outline, much that would remain hidden if we were denied their aid," are scrapped like so much old metal when their usefulness ends. So the history of chemistry, like the history of inventions, "definable as a method for utilizing a discovery," often reads like a romance.

The material value of chemistry has had to do with our wealth, health and happiness. Chemistry, by the utilization of much of the wastes of the world, has produced great wealth, as is seen in the numerous dyes, synthetic medicines, etc., which have been made from coal-tar. It has also saved injurious wastes. At some of the great copper smelters to-day, where the sulphur gases were formerly turned loose into the air to the destruction of forests, they are now converted into the cheap but valuable oil of vitriol, upon the use of which there is scarcely anything we eat, drink or wear that is not directly or indirectly dependent. In fact, one may judge the financial progress of a nation by the annual production or consumption, or both, of this acid. The industries of nations have been changed through the influence of applied chemistry. The old madder fields of France are now vineyards, the madder dye (alizarin) being made by German processes in a factory. So the millions of acres formerly given to the cultivation of the indigo plant may help feed England when they are cultivated for food products, as the Germans now manufacture a higher grade of indigo, at a lower price, than was formerly obtainable commercially from the natural sources, even with the property wages paid in India. Through the application of the principles of chemistry, better products have been produced at cheaper prices and thus made available for more people. Substances possessing little or no practical use, rare curiosities for the chemical museum, have become of great actual value. This may be seen in the development of incandescent gas lighting.

We have only recently come to an awakened conscience of fuel. The quantity of fuel required to produce the energy for an industrial process is dependent upon the manner in which it is required to do its work. Once smoke was regarded as an evil, then a nuisance; now it is known as a waste, and none has better cause to wage war against it than he who produces it. A smoking chimney is a thief, not only because it projects visible unburned carbon into the atmosphere, but in nine cases out of ten on account of the invisible gases which are hot and combustible. Regenerated gas heating not only prevents smoke, but is a powerful means of economizing heat. It has been estimated that the saving of national wealth effected by its universal application would amount to a sum sufficient to pay the aggregate national debts of all the civilized nations. What a horn of plenty may be seen outlined in the dense smoke hanging like a pall over some of our cities in this country!

The problem of energy, usually expressed in terms of fuel, is a most serious one to every nation. Upon the invention of the steam engine the days of the windmill and old-time water-wheel seemed to be numbered; sailing ships gave way to mechanically driven vessels; gas-explosion engines and electric power applied to motor vehicles

are driving out the horse, without whose aid at one time it was thought that no civilized nation could exist, and have given us a propelling force with which the air is navigated. In some ways there is a disposition to revert in part to the old order of things, as shown in the utilization of water power with improved appliances. Inventors are not without hope of utilizing the ocean tides; in fact, several installations where this is done do exist. The indefinite hope of some imaginative people that we may secure some unknown source of energy, however, is at present an undependable and gratuitous assumption. Therefore, it is of the utmost importance that the strictest economy be practiced in the expenditure of our fuel capital.

The conversion of the force of gravity into electrical energy by means of falling water has given an enormous impetus to progress in applied chemistry. Not only has it made the production of new and useful substances possible, as carborundum and artificial graphite, but it has cheapened the production of other materials, as caustics, "bleach," copper, aluminium, etc., in money values that involve large figures, and promise to render available bodies of metallic ores formerly regarded worthless. Monopolies have laid their hands upon the potash syndicates which control the natural deposits of potash salts at Stassfurt and other places, and these lay heavy tribute upon every farmer who uses mixed fertilizers. Electrical energy may yet give relief from such a tax upon every civilized person in the world, for laboratory experiments have shown the possibility of utilizing the abundant insoluble, hence unavailable, source of potash, a necessary element for plant growth, which exists in every soil, but in comparatively small, yet sufficiently large, amounts.

Perhaps the most important practical forward steps taken in applied chemistry in recent years have been along the line of the utilization of atmospheric nitrogen. No living thing, plant or animal, is known which does not contain nitrogen. Nitrogen is, therefore, necessary; it is the most expensive, yet abundant and easily wasted, element of plant food. The air contains 3,900 billion tons of this element, but it is not available, except to a limited degree, as a food. It must be properly combined with other elements for plants to feed upon it. This has recently been accomplished commercially, and its importance is realized when attention is drawn to the known sources of nitrates, and the fact is recognized that the visible supply will not suffice for the life of two generations at the normal rate of increase both in population and productivity of the soil. Fortunately, the processes devised in this day of wonderful surprises do not participate in the destruction of valuable coal deposits in obtaining the energy, but the "white coal," which, with the constant aid of nature, through the principles of evaporation and condensation, may be used over and over again. To this end it has stimulated the efforts of many toward the

conservation of the forests, for upon these depend a constant supply of water and the avoidance of devastating freshets which destroy the power plants.

The solution of problems of preventive medicine—that is, sanitation—the development of aseptic surgery, the discovery of anæsthesia, have been contributions of chemistry to human happiness. The chemist has sought and is seeking the establishment of uniform grades and international standards and agreed methods for determining them for products of exchange. Those familiar only with the secular press accounts of the struggles for pure food and drink and distinctive labels therefor realize what this means. To accomplish the refinements of this improvement in communal and international morals, however, will require a recasting of the meaning of many words in every language. This cannot fail to promote in a measure the development of a desirable universal language for all nations.

While the history of chemical economics is one of fascinating interest, it must not be forgotten that these allotments to the benefits of the living are in the end dependent upon pure chemistry. In most cases they have resulted from the application of principles derived from facts which presented no utilitarian aspect in themselves, and the principles, too, appeared to have only the remotest connection with utility. It is not intended to imply that applied chemistry has been or is entirely dependent upon pure chemistry, for there are numerous instances where what knowledge we possess in the speculative and real field of the science has received its initial impulse from some useful application.

The progress of the science has often been with a halting step. Three important misconceptions—namely, the immaterial nature of gases, the inverted notion of combustion and the material nature of heat—had first to be removed before the idea that matter is composed not only of molecules but of atoms, could gain acceptance in the beginning of the nineteenth century. By the atomic conception of Dalton (1803) different kinds of matter are dependent not only upon different kinds of molecules, but different kinds of atoms in molecules, and, furthermore, as later proved, even the configuration of the atoms within the molecules.

Various energy demonstrations, as heat, electricity and light, bring about various changes in these molecules to produce different kinds of matter. We know carbon dioxide and water, under conditions which obtain in the leaf of a tree, under the influence of light combine with the elimination of oxygen and the production of sugar. The chemist as an expert achievement can produce sugar in his laboratory, but so far he has little understanding of the chemical action of light in the laboratory of the leaf. Altho photo-chemistry

promises soon to yield results which may not be devoid of startling interest, we do not know how nature does many things that we are accustomed to see around us and attribute to a so-called vital force. In exercising the utmost care to avoid confusing the accomplished with the projected, the thesis may be reverently supported that life is energy or a manifestation thereof.

One were devoid of judgment did he not let it be clearly understood that he appreciates the objections, such as retention of form through years, reproduction of species and atavistic inheritance of character, that may be raised with reason in opposition to the mechanical, physical, chemical or energy explanation of life. As yet we do not know the constitution of the highly complicated structures of the carbon, hydrogen, oxygen, nitrogen and sulphur compounds of the nucleus—"chemical matter," as Neumeister says. The same could have been truly said of the sugars before Fischer's masterly work, beginning about a generation ago, or Osborne's more recent work upon the nucleins of wheat. Can we say, having learned the structure and synthetized the nucleus, that we shall not be able in the laboratory to give it that impulse which launches it upon a career of reproduction?

Our militant egoism need not be shocked by apparently

> Nourishing a youth sublime
> With the fairy tales of science.

We thought we knew the air, but within the last two decades it has been learned that the atmosphere contains 1 per cent. of an element never dreamed of—namely, argon. We thought every chemical atom was characterized by a distinct ability to combine with other atoms to form compounds. Argon and four other similar elements, including helium, since found, are devoid of this characteristic.

The nineteenth century gave us Crookes' tubes, which made the discovery of Röntgen rays possible and gave the hint that established the existence of the Becquerel rays, the pursuit of which eventuated in the unmasking of radium by the Curies. This remarkable substance carries enormous charges of readily detectable energy and under certain conditions changes into another element, helium (Ramsay and Soddy). The transmutation of the elements has been experimentally demonstrated. In such considerations confusion of terms must be studiously avoided. Philosophically, radium cannot be an element, because its molecule breaks up into something other than an atom of the same thing, yet it has a recognized place in the table of elements. This later fact is due to an agreement among chemists to recognize a substance as an element which, under proper conditions, exhibits a spectrum showing characteristic lines pos-

sessed by no other element and possesses a definite combining weight. Radium satisfies these two requirements and constitutes an exception to the general proposition of consistency of atoms in an elementary molecule. If we retain the term element, and there is no indication of its being discarded soon, its definition must be broadened.

A philosophic idea has come forward at intervals ever since the days when we have written records of men's thoughts—namely, that there is, or was, one, the simplest substance of which all matter is, or was made. If that be true—and perhaps it is—then we only require the knowledge of how to change one element into another and the necessary apparatus to make the idea an accomplished fact. So far, however, we have observed only the disintegration of the elements and we must yet build them up.

A knowledge of the cathode rays produced within a Crookes tube gave J. J. Thomson and Rutherford experimental data for the latest interpretations of the phenomena of radio-activity and the most modern answer to the question of "What is matter?"

Thirty years ago Crookes suggested the existence of an ultragaseous state of matter, a protyle, of which all matter is composed, and that its particle weighs about one-thousandth that of a hydrogen atom, the lightest atom known. Thomson, following an elaborate procedure, weighed these particles and found that the value was between 800 and 1,000. As they bear electric charges, he designated them electrons. Rutherford has shown that in the disintegration of radium a gas, called emanation, is produced. This, in turn, changes through several steps and continuously into helium. The change consists in hurling particles, called α-particles, at a terrific speed from the emanation. These particles are atoms of helium plus an electron, which is lost in time. By weighing before and after, the weight of the electron is determined. These values coincide with those obtained by Thomson. Etymologically, an atom means something which cannot be divided. We have been accustomed to apply the term to that chemical individual which has not yet been divided. As soon as it is shown to be complex the particle ceases to be an atom. As language changes there can be little objection, if it is done by common agreement so there may be no misunderstanding, to applying the term electron to a real atom or the real indivisible particles, for undoubtedly the atom of Dalton is complex.

Therefore, matter is composed of molecules. Molecules are made up of atoms. Atoms consist of electrons. Electrons are charges of electricity. But what is electricity? Ostwald asserts that we are aware of matter only through the evidence of energy. Matter is an assemblage of energy systems; there is no matter. All resolves itself into the mechanics of energy. Heat, electricity and life are

elementary energy systems, having definite capacity and intensity, and as chemical entities with their equivalents, represent our atomic conceptions. But here we go into the realm of metaphysics. Many of the secrets of nature have been gained, laboriously wrought for, but rich rewards await the coming generations who inherit a knowledge of the extremities of our globe but must yet learn of its interior.

Science may therefore be looked upon as a gem, beautifully cut, with its many facets. We view the light from one face, or more, with the play of colors most exquisite to the eye and gratifying to the senses. Whence the light? That is nature, the throbbing pulsation of which, controlled by some All-great, hence All-wise, Providence, makes our universe what it is, however little or much of it we may or may not comprehend.

CHARLES BASKERVILLE.

CHAPTER I

DEVELOPMENT OF THE CHEMICAL CONCEPTION

To MANY intelligent and cultivated persons not specifically instructed in Chemistry, this word recalls confused memories of colored liquids, glistening crystals, dazzling flames, suffocating fumes, intolerable odors, startling explosions and a chaos of mystifying experiments, the interest in which is proportional to the danger supposed to attend their exhibition. Further reminiscences are of many singular objects in wood, metal, glass and earthenware; of retorts and condensers, furnaces and crucibles, together with bottles innumerable filled with solids, liquids and gases. This whole bewildering paraphernalia, moreover, is connected by glass tubes of eccentric curves, displayed in inextricable confusion and meaningless array.

Behind this chaos arise vague memories of a professor or teacher discoursing learnedly in a polysyllabic jargon, and attempting to explain the unusual phenomena in words which seemed stranger than the experiments themselves. It is rarely forgotten, as H. C. Bolton suggests, how potent was the fascination exerted upon the hearer, a feeling of awe and mystery as tho the mind were approaching the border of the supernatural, impressions that have clung to chemistry ever since its entanglement with the superstitions of alchemy, astrology and the "black art."

Men and women interested in modern thought who undertake to gain thorough chemical literature a knowledge of what chemists are doing in and for the world encounter a discouraging nomenclature which repels them by its apparent intricacy and cumbrousness. Their opinion of the terminology of an exact science is not enhanced when they learn that "black lead" contains no lead, "copperas" no copper, "mosaic gold" no gold, and "German silver" no silver; that "carbolic acid" is not an acid, "oil of vitriol" is not an oil; that some sugars and some kinds of wax are alcohols; that "cream of tartar" has nothing in common with cream, "milk of lime" with milk, "butter of antimony" with butter, "sugar of lead"

with sugar, nor "liver of sulphur" with the animal organ from which it was named.

Readers of chemical writings sometimes fail to appreciate the advantage of styling borax "di-meta-borate of sodium," or of calling common alcohol "methyl hydrate," and they ignore the euphony in such words as pentamethyldiamidothiodiphenylamindiiodomethylate (a substance baptized by Dr. Albert Maasen).

Those whose chemical education consisted in attendance on a course of lectures illustrated by experiments performed in their presence, interspersed with occasional recitations from a prosaic textbook which taxed the memory in true Chinese fashion, may be pardoned for retaining very hazy impressions of the true character of the science. On the other hand, many thinking and reading persons recognize the magnitude of the scope and operations of chemistry, and have some appreciation of its benefits to mankind. It is not to be unexpected, however, that the layman's conception of chemistry in the abstract—the cold, exact, abstruse science—seems as far removed from the realms of romance as the higher mathematics. Yet mathematics and music are strangely correlated; and so it is not to be wondered at that the chemist himself, the enthusiastic master of mysteries, finds in his modern miracle making that proportion of romanticism necessary, perhaps, to the mental well-being of the individual.

The widely varying ideas which have prevailed at different periods in the history of chemical science, with regard to its nature and object, are significantly portrayed in the definitions of chemistry which have obtained at these periods, and an examination of the following collection of definitions will reveal a curious growth:

Old Proverb. "Alchimia est ars, cujus initum laborare, medium mentiri, finis mendicare." Alchemy is an art, the beginning of which is to work, the middle to lie, the end to beg.

Suidas (a Greek lexicographer of the eleventh century). "Chemistry, the artificial preparation of silver and gold."

Paracelsus (1537 [?]). "Chemistry is the art of resolving bodies."

Denis Lachaire (1540 [?]). "Chemistry (alchemy) is that part of natural philosophy which teaches the preparation of metals on the earth by imitating the operations of Nature in the earth as closely as possible."

Van Helmont (1620 [?]). "Chemistry is the art of analyzing bodies by fire."

A Chymical Dictionary, London, 1650. "Chimia is the art of separating pure from impure and of making essences."

Salmon (1672). "Chemistry is an art or a practical science

which teaches the methods of resolving compound bodies into their natural principles, and by this means rendering them most pure and most efficacious as a medicine, either for curing diseases or for perfecting the imperfect metals." ("Bibliothéque des Philosophes Chimiques," Paris, 1672.)

Lemery (1675). "Chemistry is the art which teaches the methods of separating the different substances contained in a compound." ("Cours de Chymie," Paris, 1675.)

Boerhaave (1724). "Chemistry is an art whereby sensible bodies contained in vessels (or at least capable of being contained therein and rendered sensible) are so changed by means of certain instruments, and especially fire, that their several powers and virtues are thereby discovered with a view to the uses of medicine, natural philosophy and other arts, and occasion of life." ("Elementa Chemiae," 1724.)

Pernety (1758). "Common chemistry (*chimie vulgaire*) is the art of destroying the compounds which Nature has made. Hermetic chemistry is the art of assisting Nature to perfect them." ("Fables Egyptiennes et Grecques," Paris, 1766.)

Pernety (1787). "Alchemy is a science and the art of making a fermenting powder which serves as a universal remedy for all diseases of men, animals, and plants.

"Dictionnaire Mytho-hermetique," Paris (1787). "False alchemy cannot better be defined than the act of making one's self miserable, both as regards fortune and health."

Nicholson (1795). "Chemistry as a science teaches the methods of estimating and accounting for the changes produced in bodies by motions of their parts amongst each other which are too minute to affect the senses individually; and as an art it consists in the application of bodies to each other in such situations as are best calculated to produce those changes." ("Dictionary of Chemistry," London, 1795.)

H. Davy (1802). "Chemistry is that part of natural philosophy which relates to those intimate actions of bodies upon each other, by which their appearances are altered and their individuality destroyed." ("Lectures" in Collected Works, vol. ii, 1839.)

Thomson (1810). "The object of chemistry is to ascertain the ingredients of which bodies are composed; to examine the compounds formed by the combination of those ingredients; and to investigate the nature of the power which occasions these combinations." ("System of Chemistry," 1819.)

Frankland (1866). "Chemistry is the science which treats of the atomic composition of bodies and of those changes in matter which result from an alteration in the relative position of atoms." ("Lecture Notes for Students," London, 1866.)

Rodwell (1873). "Chemistry is the science which treats of the various kinds of matter, whether simple or compound, their properties and the laws which govern their combination with and separation from each other." ("Birth of Chemistry," London, 1873.)

Roscoe (1873). "The science of chemistry has for its aim the experimental examination of the properties of the elements and their compounds, and the investigation of the laws which regulate their combination one with another."

Ostwald (1890). "Chemistry is the science which treats of the different forms of matter, their properties, and the changes which they undergo."

Mendeleeff (1891). Chemistry is concerned with the study of the homogeneous substances or material of which all the objects of the universe are made up, with the transformations of these substances into each other, and with the phenomena which accompany such transformations."

Remsen (1892). "The science of chemistry has to deal with everything connected with the deepest-seated changes in composition which the different forms of matter undergo."

At the present time, chemistry is usually defined as the study of matter and the changes produced in it by the action of chemical force or other forms of energy upon it. It rests upon a secure basis of fact, and its first object consists in learning the constituents of which the material world is composed, in reducing these constituents to their simplest forms, and in building up new chemical compounds from the latter. These problems, along with the task of determining the laws governing the chemical combination of matter, occupy the time and thought of the chemists of the present day.

The Egyptians, Hebrews, Phœnicians and other ancients acquired a certain indefinite knowledge of chemical processes in a purely accidental manner, which were applied for the practical results obtainable, but no explanation of these processes was deduced. Neither did the Greeks and Romans make any attempts to collate facts then known or to pursue the investigation of natural phenomena for the attainment of a definite purpose, nor before the fourth century of the present era were endeavors made to gain an insight into chemical processes by experiment. Such a lack of data did not prevent the peoples of antiquity from speculating on the nature of matter, however, and their views upon the ultimate constituents, or "elements," of the organized world have given the first age of chemistry a characterizing feature.

Altho there is no positive evidence that the Greeks and Romans were acquainted with a belief in the production of precious metals from

base metals, yet the theory that one element can be transformed into another was developed from the ancient doctrines of the nature of the elements, and at the beginning of the present era, primarily in Egypt, attempts were made to transform the base metal into gold and silver. The art of transmutation was termed "chemia," a word which is probably derived from the North Egyptian name for Egypt (von Meyer). This term is mentioned by Plutarch as the name of Egypt, but there is some diversity among etymologists whether the present word "chemistry" is derived from the Egyptian word; the Arabic "kema," meaning secreting; the Sanskrit "kema," meaning gold; or the Greek "chymos," meaning fluid.

Alchemy, which is derived from the Arabic "al-kimija," an agent for effecting transmutation, had for its object the solution of the problem of transmutation, the attainment of the so-called "philosopher's stone," by the aid of which metals were to be transmuted and the life of man prolonged. This task characterized the Age of Alchemy, a period extending for at least twelve centuries. This age was one of magic and necromancy, but effected the extension of the knowledge of chemical facts.

The next period in the history of chemistry is known as the Iatro-Chemical, or the period of medical mysticism. This period extended from the first half of the sixteenth century to the middle of the seventeenth century and was characterized by the absorption of medicine by chemistry. However, chemistry did not lose its alchemistic tendencies and was not yet an independent branch of natural science.

After the Iatro-Chemical Period occurred a transition period and chemistry became a science. This period is known as the period of the Phlogiston Theory, owing to the fact that the chemists at the end of the seventeenth and during most of the eighteenth century attempted to explain the phenomena of combustion by assuming the existence of a hypothetical principle of combustibility, "phlogiston."

The early part of the most recent period in the history of chemistry is characterized by the decline and fall of the phlogiston theory and its replacement by the anti-phlogistic chemistry of Lavoisier, which laid the foundation of the new chemistry, a science which covers the era of quantitative investigation. This era has had for its guiding star the chemical atomic theory, and the immense strides made in the science during the latest epoch are due to the exact study of chemical composition and the close investigation of physico-chemical relations.

CHAPTER II

THE CHEMICAL KNOWLEDGE OF THE ANCIENTS

IN endeavoring to find traces of a science in the earliest historic times, the mind must be free of the idea that the ancient presentment will be similar to the modern form as it is known to-day. The ancients possessed a knowledge of isolated scientific facts and occasionally formulated crude theories, but it is exaggeration to speak of systematic science as existing among them. This was due to the fact that they preferred to advance from the general to the particular, instead of drawing general conclusions from accurately observed facts, since they were disinclined toward experiment and overfond of speculation. The position of the natural sciences in the early times, particularly that of Chemistry, is sufficient to show the manner in which errors were introduced and became firmly established as a result of following the purely deductive method, which Aristotle deemed the road that should lead to the desired goal.

Venable very appropriately speaks of the birth of Chemistry in terms analogous to the development of the ovum, which will lead through a series of metamorphoses up to the perfected insect; and Rodwell compares the study of the transformations occurring at various periods in the development of Chemistry with the study of the history of a nation. Certainly there occurred the primary groping after causes, struggles to frame laws, and revolutions; and it is informing to follow the progress of Chemistry much as may be traced the history of a people's growth.

The beginnings of Chemistry are lost in the haze of the remote past and unquestionably date back thousands of years to the time when the pressing needs of man taught him to adapt to his own ends the means and materials placed at his disposal. It is interesting to note that woman was the first to receive instruction in chemical lore, according to tradition and legend. In the apocryphal book "Enoch," originally written about 115-120 B.C., an account is given of the relations existing between angels and terrestrial folk, and it is stated that one of these angels, Azazel, taught women the making of jewelry and the use of rouge, as well as imparting not a little information concerning the metals and precious stones of the earth. This legend also is met with in writings of the third and fourth centuries, and

even in those times chemistry was held to have been imparted to mankind in a remote past.

The question of the ultimate constituents of bodies or elements occupied the minds of the oldest nations, and the primary conceptions of these elements occurred in the mythical times before Empedocles and Aristotle. The word element is derived from the Greek word "elephas," which was changed by circumstances to "elebas," "elemas," and then to "elementum," the Latin equivalent.

In Babylonia it was believed that what was in the heavens was also in the land and in all portions of it, and the Babylonians considered that a relation existed between the heavenly bodies and colors. They soon observed that certain relations existed between terrestrial phenomena and the deportment of the heavenly bodies, and this observation led them to suppose that the first conceived elements—fire, water, air and earth—were controlled by preternatural powers. As might be expected from the similarity in their efforts in accounting for the origin and formation of the universe, the Egyptian conception of the elements was similar to the Babylonian.

The oldest writings of India teach that the world was made of wind, water, earth, fire, and a substance of immaterial nature, ether. In the Laws of Menu the subtle ether is spoken of as being the first created, and from this, by transmutation, came air, and this through some change became light or fire, and by a further change in this came water, from which lastly earth is deposited. This theory was accepted by the Brahmans and Buddhists and found its way into Europe. In the "Anguttara Nikaja" consciousness is named as a sixth element, and in the writings of Kapila, the leading exponent of the Samkhya philosophy, it is stated that there are five subtle particles, rudiments or atoms—perceptible to beings of a superior order but unapprehended by the grosser senses of mankind—derived from the conscious principle and themselves productive of the five grosser elements, earth, water, fire, air and space. Kanada, who founded the Nyaya system of philosophy, proposed an atomic theory in which he states that atoms are eternal and that the ultimate atom is simple.

One of the oldest of the Chinese classics, the "Shu King," contains a document of still greater antiquity termed "The Great Plan with Its Nine Divisions," the first division of which speaks of water, fire, wood, metal and earth as the elementary substances which went to build up the universe. This document probably depicts a belief five thousand years old and it is known that the above mentioned substances were regarded as elements in the dynasty of Hoang-Ti (2698-2599 B.C.). In that most obscure Chinese classic, the "Yi-King," fire and water, wind and thunder, the ocean and the mountains, appear to be recognized as the elements.

The most complete theories of the ultimate constituents of bodies

have come down from the Greeks, although it is highly probable that the Greek philosophers did not themselves deduce their theories of atoms and elements, but derived them from other sources. Some have maintained that the Pythagorean theories are derived from the philosophy of the Chinese; but, since the Greeks came from Asia as did the other Indo-Germanic races, it is natural to suppose that they brought various Eastern theories with them, modified them according to their environment and developed them by their own powers.

The earliest Greek cosmogonists were those of the Ionic school, which was founded by Thales of Miletus, who lived about 600 B.C. Thales considered that water was the material cause of all things, and was ignorant of the atmosphere or air. Such views, as well as those of Anaximenes and Heraclitus (in the sixth century B.C.), who ascribed to air and fire respectively the rôle of ground material, have had no influence upon the development of chemical knowledge.

Leucippus, who lived in the fifth century B.C. and who is regarded as the founder of the Atomistic school, considered that all things consisted of spaces and atoms, the latter being further indivisible, having only quantitative differences between one another and being always in motion. This theory was further developed by Democritus of Abdera, who took a primal element as the basis of his speculations, but subdivided this further in that he imagined it to be made up of atoms, which differed from one another in form and size, but not in the nature of their substance. According to him, all the changes in the world consisted in the separation and recombination of these atoms.

Empedocles of Agrigent (500 B.C.) regarded the "elements" air, water, earth and fire as the basis of the world, and maintained the constancy of matter. He did not speak of the derivation of the elements from a single substratum or of ultimate atoms, and in his system the contending forces cause the combination and separation of the elements.

The system of natural philosophy of Plato (427-344 B.C.) has been practically without influence on the development of physical science. Plato assumed the existence of the four elements of Empedocles and propounded mathematical doctrines concerning these elements, but disregarded certain difficulties pointed out by subsequent philosophers. His pupil, Aristotle (384-322 B.C.), however, among the most famous of the Greek philosophers, is deemed the sage who exercised the most influence upon subsequent thought. Aristotle considered that four elements were insufficient in themselves to explain the phenomena of Nature; he therefore assumed a fifth one, which he imagined to have an ethereal nature and to permeate the universe.

The followers of the Aristotelian doctrine in the Middle Ages supposed this "element" to be material, the "quinta essentia," and made

many endeavors to isolate it, causing endless confusion. The Stagirite considered the properties of bodies to be the result of the simultaneous occurrence and intermingling of fundamental conditions, and regarded the component elements only in the sense of bearers of these fundamental properties. He held that the chief qualities of the elements were those apparent to the touch, as warm, cold, dry and moist, and maintained that each of the elements of Empedocles is characterized by the possession of two of these fundamental properties, air being warm and moist, water moist and cold, earth cold and dry, and fire dry and warm. He concluded, therefore, that the differences in the material world were to be attributed to the properties inherent in matter and that the elements can change one into another.

In Aristotle's opinion, the transmutation of the elements happens owing to the abstraction of certain qualities and the substitution of others; hence, he concluded that an element can more readily change into one with which it has one quality in common, as cold water to cold earth and hot fire to hot air, than into one completely its opposite, as hot, dry fire to cold, wet water. Aristotle regarded the change of water into steam as a transmutation of the elements, a qualitative change of material, as otherwise he could not explain the great change of bulk if the steam had previously existed in the water without change or difference. Views of this nature on the states of the aggregation of matter led to the idea of transforming one kind of matter into another, and the generalization of the Aristotelian ideas fostered the belief in the possibility of the transmutation of metals, a particular feature of the alchemistic period.

It is unnecessary to point out how widely the above mentioned views with regard to the elements deviate from the conceptions of modern chemistry, yet the Greek philosophers, with the freedom and boldness of the Hellenic mind, and an ability to infer and enunciate, had grasped the idea of elemental substances, elements out of which all things were made—the principles of things—and had thought out the existence of atoms as the ultimate constituents of matter. The belief in the existence of the Hindu and Aristotelian element ether was and still is assumed as a necessity for explaining many phenomena. Various chemical facts had been learned by empirical methods and by accident, but the Greeks overvalued the deductive and undervalued the inductive method, and held aloof from the observation and practice of chemical processes.

In the earliest records of the Egyptians, Jews and Hindus there is to be found an acquaintance with the working of different metals, which art was held by the younger of those nations to have been taught by mythical personages. On reference to the drawings found on the tombs in Egypt, figures are shown therein illustrating the art of metallurgy, and it has been learned that the operations were con-

ducted by weighed portions of matter. Moreover, Biblical history records that the Jews were acquainted with gold, silver, copper, iron, and probably lead and tin, and that a form of balance was used for weighing metal. The Greeks and Romans were familiar with many metallurgical processes, but made no attempts to explain the chemical processes involved in the smelting of ores.

The ancients believed that the metals were produced by the penetration of air into the vitals of the earth, and assumed that the amount of metal increased as the mine proceeded inward. This conception was based on the testimony of Aristotle and was entertained for a long time.

Gold and silver were the metals earliest known and were valued highly in the early times. The gold mines of Nubia were worked by the Egyptians, and in the time of Rameses II. these mines yielded gold to the value of $600,000,000 per annum. The Phœnicians obtained gold in Eastern Africa and were the first to mine gold on the Island of Thasos. The malleability of gold rendered it possible for the ancients to gild objects by covering them with thin sheets of the metal, and they later learned to produce a layer of gold on objects by dissolving the metal in mercury and heating the amalgam produced. The older nations were acquainted with processes for freeing gold from admixtures, as there are extant records of purifying gold dust by melting it with lead and salt for some time, a method practised at a very early period and referred to in various parts of Scripture. Pliny describes the purification of gold by means of mercury, and the process used in his time was similar to the amalgamation process practised at the present day. In general it may be stated that the old and new methods of obtaining gold differ in details not in principle.

Silver was supplied to the ancients by the Phenicians, who worked the Rio Tinto mines in Spain, the native silver mines of Laurium, and the mines in Armenia. According to Posidonius, silver was discovered in Spain by the forests taking fire and melting some of the ore in which the precious metal was imbedded. Strabo states that silver was purified by fusion with lead, but it does not appear that the separation of silver from gold was known before the present era. Beckmann states that the ancients used an alloy of gold and silver, afterward termed "electrum," because they were unacquainted with the art of separating these metals, and it is known that an amalgam of gold and silver was regarded in ancient times as an individual metal, being termed "asm" by the Egyptians.

Copper has been known from the earliest times, and some authorities consider that it was the next metal after gold which man learned to extract and reduce. The present state of archeological research does not suffice to locate all the principal copper mines of the ancients

nor to compute the quantity of metal which they yielded, but it is believed that both the Hindus and Chinese made coins of this metal at a period which may be fixed approximately at about three thousand years ago. Copper was one of the greatest articles of commerce with the Phenicians, who derived a large supply from the mines of Nubia, which at one time supplied the whole of the western world. They combined with it the tin obtained from the islands of Cyprus and Britain to make the bronze of commerce, which was early used for making weapons, ornaments and utensils; and the ancient civilized nations were acquainted with bronze before they had learned to prepare tin in a metallic state. Palmer states that it is evident that the copper mines in the neighborhood of Serabit el Khadim and Magharah, in Egypt, were in full working order at the time of the Exodus; and Bauerman is authority for the statement that the period over which the working of the copper mines at Wady Magharah extends, according to hieroglyphic evidence, is from the third to the thirteenth Manethonian dynasties. With regard to the smelting processes by which the "aes," or copper, of the ancients was obtained, nothing certain has as yet been ascertained.

The concurrent testimonies of Hindu, Assyrian, Babylonian and Greek tradition, as well as its own etymology, fix the discovery of iron—that is to say, the invention of smelting iron ore and of manufacturing iron and steel, or the escape of the invention from the temples—at a period not earlier than the fifteenth century B.C. Among others, Brahma, Krishna, Nin-Ies, Jason and Osiris were credited with the invention of iron. Lepsius is authority for the statement that iron has been in use in Egypt for more than five thousand years, and it is well known that the Egyptians early learned to temper iron, which they employed for the manufacture of a variety of hard instruments.

Kirchmaier, a writer of the seventeenth century, hazarded the conjecture that Adam was the first to use iron for economic purposes, to which opinion there are no satisfactory objections based on evidence. The ancients prepared iron from brown iron ore and magnetite in smelting furnaces, but no particulars are vouchsafed as to the actual process used. However, old Roman iron smelting furnaces have recently been unearthed near Eisenberg in the Pfalz, and the form of furnace used by the Egyptians may be judged from various inscriptions.

Lead was used by the Romans for making water pipes, writing tables, and coins, and soldering with lead or with an alloy of lead and tin was also well known. The Romans worked the lead ore deposits of Britain, but little is known with regard to the smelting processes used. Tin was prepared quite pure in olden times and was used in the preparation of two important alloys, solder and bronze. The

Phœnicians obtained tin either from India or Britain and the Israelites procured some from the Midianites. Among the Romans lead and tin were distinguished from one another as "plumbum nigrum" and "plumbum candidum." "Stannum," the present Latin word for tin, signified an alloy of tin and lead.

Brass, an alloy of zinc and copper, was first described by Aristotle and was long regarded as copper which had been colored yellow by fusing it with "cadmia," an ore of zinc often mentioned in ancient writings as having been found in Cyprus, but was not recognized as an alloy to a much later date, and zinc as an individual metal was not known to the ancients. The name "cadmia" is said to have been derived from Cadmus, who is reputed to have introduced the making of brass at Thebes, but this is doubtless incorrect. "Cadmia" was also used as a medicine as early as 300 B.C.

When the metal mercury, or quicksilver, was first discovered is not known, but its preparation from cinnabar by means of copper and vinegar is mentioned by Theophrastus (about 300 B.C.) and it was known at least as early as Aristotle's time. Some writers consider that in the passage in the Bible where Moses directs that all the metals taken from the Amalekites should be made to pass through the fire and afterward to be "purified by the water of separation," that this "water of separation" was mercury, but this is not based on fact.

Dioscorides describes the production of mercury from cinnabar and iron, and Pliny refers to the purification of mercury by forcing it through leather. The ancients were aware of the fact that mercury "attracts particles of gold and unites with them," and Vitruvius describes the manner of recovering gold from cloth in which it has been woven by this means. The principal ore of mercury, cinnabar, mercuric sulphide, would not fail to attract the attention of the crudest folk by its brilliant red color, and there are sufficient evidences to show that it was used as a pigment or paint by the Romans, Ethiopians and Jews.

Glass, the transparent solid formed by the fusion of siliceous and alkaline matter, was known to the Phenicians and constituted for a long time an important manufacture of that people, because of its ingredients—natron, sand and fuel—abounding upon their coasts. The art of making glass, however, originated in China and Egypt, and its discovery in the last mentioned country was accidental, soda having been added as a flux to sand containing gold for the purpose of extracting the latter. Glass ornaments have been discovered in Egyptian tombs which are as old as the days of Moses, and Pliny and Strabo give accounts of the famous glass works of Sidon and Alexandria. The Greeks acquired the art of glass making in the fifth century B.C., and the Romans used glass for windows, mirrors and various other purposes. Rawlinson states that transparent glass was

brought into use, or at least the oldest specimen found is, in the reign of Saragon II., 710 B.C.

The artificial coloring of glass by metallic oxides was discovered at a very early date, and remains have been found in ancient Egypt which indicate that methods for producing enamels and artificial gems were known. Ancient profane authors make mention of immense emeralds which are considered now to have been made of glass, and Pliny states that beryl, opal, sapphire, amethyst, etc., could be imitated, but that these imitations were softer and lighter than the real gems. The art of engraving on glass was also known in ancient times and the ancient Assyrians cut gems with great skill.

The art of pottery presents a more ancient and closer alliance between art and utility than any other branch of manufacture, and the date at which this art began to show itself is lost in the darkness of remote antiquity. The old Egyptians understood how to coat their earthen vessels with colored enamel, and porcelain was discovered and employed by the Chinese at an early date. The potter's wheel is probably the most ancient mechanical appliance which industrial art has invented.

The people of ancient times prepared soap by the action of alkalis on fats, and drew a distinction between soft and hard soaps, according as potash or soda was used in the manufacture. According to Pliny, the soap in Germany and Gaul was prepared from animal fat and a water extract of plant ashes strengthened by adding lime.

The art of dyeing no doubt originated in that love of distinction inherent in the human mind, inducing man, for its gratification, to stain his dress or his skin with the gaudy colors of the vegetable kingdom, and was practised very long before any views were entertained as to the nature of the changes which occurred in the chemical processes involved. The Egyptians developed dyeing with some degree of scientific precision, as they were acquainted with the use of mordants, learning that alum imparted no color itself but fixed certain dyes on cloth, and perfected the dyeing of purple.

Tyre made dyeing one of its principal occupations, and it has been asserted that the invention of the celebrated dye, Tyrian purple, was made in that city. The discovery of this purple dye is said to have been made 1,500 years before the Christian era, and Pliny states that the juice for communicating it was obtained from two different kinds of shell-fish. Kermes, indigo, madder, archil, safflower, alkanet, henna, broom, galls, walnut, pomegranate seeds, Egyptian acacia and litmus were used as coloring matter in the ancient times. In Pliny's time, white lead, cinnabar, vermilion, smalt, verdigris, hematite, soot and indigo blue were used for painting, and ink was prepared by mixing soot with gum. Galena (sulphide of lead) and realgar and orpi-

ment (sulphides of arsenic) were used for pigments and medicines, notwithstanding the fact that their poisonous action was known.

The Egyptians were the first to use chemical preparations for medicinal purposes. Verdigris, white lead, litharge, alum, soda and niter were employed in making medicaments, and lead plasters were made from litharge and oil. Iron rust was a very old medicine; and Homer speaks of sulphur being burnt to expel the evil spirits from a home. It was also used for purifying clothes, conserving wine and for destroying foul odors.

Among other substances whose application dates from a very early period may be mentioned lime, which was burnt and used in making mortar, and for causticizing soda for soap making; soda and potash, which were used in washing, glass making and soap making; bitumen and asphalt, which were employed for cements, torches and embalming; and acetic acid in the form of crude wine vinegar, which the ancients assumed as being present in all acid plant juices and considered to be a powerful solvent. Among the other organic compounds known at the beginning of the Christian era and possibly before then, were sugar, starch, petroleum, oil of turpentine, and various fatty and ethereal oils. Sugar was obtained from the sugar cane, starch from wheat, and the fatty oils (olive, almond and castor oils) were pressed from seeds and fruits. Oil of turpentine was prepared by distilling pine resin. The ancients were familiar with beer, wine and bread making, but did not, with their disinclination toward observation, know that alcohol and a gas different from air (carbonic acid) are formed during such processes of fermentation.

The fact that wine yielded an inflammable substance was noted by Aristotle however; but this body was not isolated.

The most ancient Latin treatises on chemical technology are the "Compositiones ad Tingenda," dating from the close of the eighth century and the "Mappæ Clavicula," written before the tenth century. In the first-mentioned work, a very rational grouping of substances occurs; the minerals and earths are by themselves; then follow gums, resins, and other products of plants; and thirdly, substances derived from the ocean.

CHAPTER III

THE EARLY ALCHEMISTS

The origin of alchemy undoubtedly is to be sought for in remote antiquity, as mythical tradition reveals the sources from which the belief in the transmutation of metals was nourished, and the primary historical sources are rare and obscure. However, it appears that alchemy was pursued as a secret science, held in honor, among the Egyptians, Chaldeans and other nations.

The almost universal tradition among alchemists is that their art was first cultivated among the Egyptians; and when it is recalled that ancient Egypt was a country where the chemical art was widely practised, it is not surprising that the earliest records of alchemy are to be found there. Clement of Alexandria states that the knowledge of the art was confined to the priests, who were prohibited to communicate it to any but the heir-apparent to the throne and to such among the priestly caste as were virtuous and wise; and Plutarch mentions that the strictest secrecy was observed. It would seem that the art of alchemy was especially cultivated at Memphis, and Ptahmer, the high priest of Memphis, was so great an adept that he was said to be familiar with all things.

The first dominant personality with which the origin of alchemy is associated is that of Hermes Trismegistus, and the alchemists acknowledge him as one of the earliest masters, if not the originator of their creed and craft. This Hermes, some assert, is identical with Canaan, the son of Ham, and the name is synonymous with the old Egyptian godhead Thoth, which, when endowed with the serpent-staff as the symbol of wisdom, was compared by the Grecians with their Hermes. Hermes Trismegistus was said to be the author of twenty thousand or more books, which probably indicates that, as the god of letters, all books were dedicated to him, and in Roman Egypt pillars were erected in his honor, upon which alchemistic inscriptions were put in the form of hieroglyphics.

In the eleventh century the alchemist Hortulanus announced the Latin version of an essay which he ascribed to Hermes. This came to be known as the "Smaragdine Table," or "Tabula Smaragdina," and it is probably one of the earliest of the Hermetic philosophical

or alchemistic writings. An English translation of this essay is as follows:

> "True it is without a lie, sure and most true; what is below is like that which is above. And what is above is like that which is below, of one substance to perform miracles.
>
> "And as all things have come from one being, the meditation of one, so all things have been generated from this one thing by adoption.
>
> "Its father is the sun, its mother is the moon. The wind has carried it in its womb. Its nurse is the earth. The father of every talisman of the whole world is this. Its power is unimpaired when it is turned upon the earth.
>
> "Separate the earth from the fire, the subtile from the material, gently, with great cleverness. It rises from the earth to heaven and again descends upon earth, and receives the force of those above and those below.
>
> "Thus thou wilt have the glory of the whole world. All obscurity, therefore, will leave thee.
>
> "This is of all strength the strong strength, because it will subdue every subtile thing and penetrate every solid.
>
> "Thus has the world been created. Hence there will be wonderful adoptions whose measure is this.
>
> "Therefore I have been called Hermes Trismegistos, possessing three parts of the philosophy of the whole world.
>
> "What I have said of the operation of the sun has been fulfilled."

This essay is obscure enough to receive almost any interpretation. The Chaldeans, who were masters of occult sciences, undertook the fusion of astrology and magic, and the belief in the connection between the sun and planets and the metals, which was assumed for a long period, was of Babylonian origin. It was believed that the planets influenced a growth of the metals, and the signs of the heavenly bodies became the symbols of the metals; in fact, the metals were called by the names of the stars up to the end of the eighteenth century. One writer of the fifth century A.D. states that gold corresponds to the sun, silver to the moon, lead to Saturn, tin to Mercury, iron to Mars, and copper to Venus.

In the thirteenth century symbols were used freely to denote some of the metals; as, for example, gold, Sol, was represented by a circle with a dot in its center; silver, Luna, was depicted by a crescent; and copper, Venus, was denoted by the symbol used by Glauber at a later date. Many of the alchemists saw in these symbols an indication of the metals they represented. Thus the circle illustrated perfection of the metallic condition, while the semi-circle indicated only an ap-

proximation to this state. Some have supposed that the symbol for copper, Venus, represented a hand mirror, and this is highly probable.

The Jews, who were believers in magic, played an important part in the fusion of eastern and western doctrine at the time of the birth of Christianity, and some writings on alchemy have been ascribed to Jewish writers. The later alchemists recorded various Biblical characters as alchemists on the authority of the Bible, as Adam, Tubal-Cain, Moses and his sister Miriam, and John; and referred the origin of alchemy to the time before the flood.

Democritus (460-357 B.C.) is the earliest historical personage connected with alchemy, but it is not known how much of the alchemical knowledge of the ancients should be assigned to him. His name is found in the magic ritual of the Leyden papyrus (found in Thebes in the third century A.D.), and, according to Pliny, he received instruction in magic from Ostanes the Mede.

During the first centuries of the present era, the transmutation of copper into gold was thought to be an ascertained fact, and the works of Pliny, Dioscorides, Zosimus, Aeneas Gazaeos and Themistos Euphrades furnish records of this belief, which probably originated in the production of alloys possessing the color of gold or silver. Kopp has pointed out that it is probable in early times a plating of gold or silver may have been considered an actual transmutation of the covered object.

In the early part of the Christian era, alchemy attained much notoriety and was fostered by the Church. In fact, the records of alchemy go on increasing from this era, and the savants of the time have left us fragments of their works. First among the alchemists of the early part of the Christian era is Zosimus, who lived in the third century. In his "Manipulations," comprising twenty-eight books, he speaks of the fixation of mercury, of a universal medicine, and of a tincture which possessed the property of converting silver into gold. Zosimus is spoken of with great esteem by the later alchemists, and his mystical language exercised a pronounced influence on the Alexandrians and medieval alchemists. Synesius, Bishop of Ptolemais, wrote commentaries on the works of Zosimus; he lived in the fourth century.

Olympiodorus, a native of Thebes, reproduced the philosophy of Thales and Anaximenes, and was the first to distinguish matter according to its combustibility. His works, however, do not contain any certain information with regard to definite operations.

Until the fourth century Alexandria had been the center of science and philosophy, but under Roman rule it gradually declined, so that at this time only the Temple of Serapis was left. This temple, which was the bulwark of medical and alchemical study, however, was destroyed in the reign of Theodosius, so that many books which would

have been invaluable for the history of chemistry were lost through its destruction. The Serapeum of Memphis and the Temple of Ptah also were destroyed at the same time as the Temple of Serapis, and it is only due to the relations which before then were developed between the Egyptians and the Byzantine Empire that all acquaintance with chemistry was not obliterated. Notwithstanding these catastrophes, the knowledge of some chemical operations continued to exist in Egypt, even tho the light of science was gone and adepts no longer taught their cult, and the conviction that the base metals could be transmuted into gold and silver, with its alluring possibilities, still remained a feature of Egyptian thought.

At the period when ignorance and barbarism prevailed through every part of the Roman Empire, Greek learning found an asylum among the Saracens. About the middle of the eighth century the second prince of the Abbassidean dynasty, the caliph Al-Mansur, founded the city of Bagdad and the light of philosophy dawned upon Arabia. Al-Mansur studied astronomy under the direction of two Christian physicians at his court, and offered liberal rewards to those who would undertake the translation of the Greek works on philosophy and science, which work was executed by the Christians then resident in Bagdad. He also founded a university at Bagdad, and pupils and professors flocked to it from all parts. Greece, Persia and India were taxed to help the Arab mind, India especially providing many alchemical notions.

The succeeding caliphs, Harun al Raschid and Al-Mamun, also were liberal patrons of learning of every kind, and under the caliphate of the latter the light of philosophy shone forth in meridian splendor. Science continued to enjoy the protection of the Saracen princes even after the empire was divided into several caliphates, and was, by means of their conquests, disseminated throughout the greater part of the world. From the beginning of the ninth to the end of the thirteenth century, when the power of the Saracens yielded to that of the Turks, schools of learning flourished in the empire, and the college at Bagdad contained 6,000 masters and scholars at the beginning of the twelfth century.

About the year 1000, twenty schools were instituted at Cairo and learning was imparted to a multitude of pupils. Academies were also founded in Africa and Spain, and these were distinguished by eminent philosophers when barbarism universally prevailed among the western Christians. The library of the University of Cordova contained 280,000 volumes, and it is said that this university produced 150 authors.

Altho Islamism prohibited magic and all arts of divination, alchemy applied to the preparation of medicines was ardently studied and it found its way to the other Western nations, where from the Arabian

universities in Spain it attained its full development in the thirteenth century.

The first of the "alchemical adepts" who appeared during the Christian era was the so-called founder of experimental chemistry, Abou Moussah Djafar al Sofi, afterward known to Western nations by the name of Geber. This alchemist is supposed to have lived in the eighth century, but his life is involved in hopeless obscurity and he has sometimes been confused with Dschabir of Tharsis. However, some historians of chemistry have ranked him first among the chemists and alchemists who flourished prior to the time of van Helmont, and it has been remarked that "Geber is to the history of chemistry what Hippocrates is to the history of medicine."

No less than 500 treatises have been attributed to Geber, and these are supposed to have included all the physical sciences; but the recent researches of Berthelot and others have proved that the Latin writings hitherto ascribed to Geber could not have been written by him. The oldest of these writings, the "Summæ Perfectionis magisterii in sua natura Libri IV," was not written till the middle of the fourteenth century, and it appears that the "De Investigatione perfectionis Metallorum," which was formerly thought to contain two important literary productions of Geber—his testament and a tract on the construction of furnaces—belongs to an even later date.

Berthelot further has shown that the Arabic manuscripts of the authentic Geber prove that he did not really profess the remarkable knowledge attributed to him, but that he adhered to the Greco-Alexandrian alchemists. His real views were mystical. For instance, he believed in the influence of the planets upon the metals, and his reasoning was mostly from premises which now appear defective. The Latin treatises, with which, until the investigations of Berthelot, the name of Geber has been connected, contain views on sulphur and arsenic, and on the transmutation of metals; in fact, they would make it seem that the object of his work had been the discovery of the Philosopher's Stone, but it is now known that these writings contain the collected knowledge of the four or five centuries after the time of Geber.

Rhazes, whose true name was Mohammed-Ebn-Secharjah Aboubekr Arrasi, was a celebrated disciple of Geber. He was born about the year 850, and no less than 226 treatises are said to have been written by him. These writings discuss the influence of the stars on the formation of metallic substances beneath the earth, and contain, some assert, the first mention of borax, orpiment, realgar, and certain combinations of sulphur, iron and copper, as well as some salts of mercury and compounds of arsenic (Figuier). He believed in the transmutation of metals and undertook to perform a transmutation before Emir Almansour, Prince of Khorassan, after the latter had spared

no expense in providing the necessary apparatus and materials for the accomplishment of the "magnum opus." He failed miserably, however, and subsequently died in poverty and obscurity.

The next great Arabian scientist was the illustrious Ebn Sina, generally called Avicenna, who was born about 980. He is believed to have died in the year 1036, altho several Oriental peoples assert that he is still alive and enjoying the nectar of perpetual life and untold wealth, results of the surcharged power of the Philosopher's Stone. Six or seven treatises on alchemy have been ascribed to Avicenna. One of these, the "Tractatulus Alchimiæ," treats of the nature of mercury, which Avicenna regarded as the universal vivific spirit, capable of penetrating, developing and fermenting. Avicenna undoubtedly derived his chemical knowledge from Geber. According to Waite, he describes several varieties of saltpeter and treats of the properties of common salt, sulphur, orpiment, vitriol and sal-ammoniac.

Among the other disciples of Geber may be mentioned the Arabian physicians Avenzoar, Averrhoes, Maslema and Abukases, and the philosopher Alfarabi. Avenzoar, who lived in the eleventh century, is said to have made some additions to the knowledge of medical preparations, while Averrhoes, a physician celebrated for his personal virtues, attempted to improve the theory of medicine by the aid of philosophy and attained some prominence as a chemist. A North Persian physician, Abu Mansur, wrote a work on the principles of pharmacology, by which may be ascertained the chemical knowledge of the time, but it appears that the Arabian alchemists of the eleventh, twelfth and thirteenth centuries mostly devoted themselves to attempts at transmuting the base metals into gold. These alchemists, in the main, were of little prominence and contributed nothing new.

At the beginning of the seventh century almost the whole Western world was overwhelmed with intellectual darkness, and in the eighth century philosophy and learning seemed ready to expire among the Greek Christians. However, the spirit of barbarism which possessed many of the reigning emperors was not characteristic of the reigns of Michael, Bardas and Constantine Porphyrogenetes, all of whom, excited by the example of the Saracen caliphs, recalled and encouraged learning. Constantine was himself, in the ninth century, the pupil of the Byzantine scholar Michael Psellus, who contributed to the propagation of alchemistic ideas.

From the eleventh to the fifteenth century philosophy and learning were much neglected in the Greek empire, but at the time when Constantinople was taken (1451) there were several learned philosophers among the Greek Christians. These were obliged to leave their monasteries, however, and this circumstance occasioned the return of Grecian learning into Europe; for after the Greek empire was destroyed by the Turks, the friends of literature and science fled into

Italy, taking with them many of the Egypto-Greek and Arabian alchemistic doctrines.

Notwithstanding the fact that the decadence of Saracen power in Europe was rapid after the expulsion of the Arabs from Spain, yet for some centuries the influence of Arabic thought was great. The works of the Arabians were translated and widely disseminated, and the modes of their thought and work imitated. Then, too, the returned crusaders aided in the spread of Eastern learning and many industries were founded by them. They were particularly interested in alchemy, however, and as the nobles were impoverished and desired to replenish their treasuries, attempts at transmuting the base metals into gold became more than a craze—it became the cardinal point toward which all chemical knowledge was directed.

Many Christian princes were imposed upon by pretending possessors of the Philosopher's Stone. It is especially interesting to note that the first appearance of an alchemist at a German court was about the year 1063, when a baptized Jew announced to Adalbert von Bremen that he had acquired in Greece the knowledge of transmuting copper into gold.

It was during the thirteenth century that learned men gave their attention to the study of alchemy, and consequently the art reached a high degree of development. These scholars considered that the transmutation of the metals was a settled fact and maintained the existence of the Philosopher's Stone, and some of them—Albertus Magnus, Thomas Aquinas, Roger Bacon, Arnold Villanovanus and Raymundus Lullius—greatly influenced the development of chemistry by their pursuit of alchemy in a scientific spirit.

Albertus Magnus (1193-1280) was a scholastic theologian, but his genius and curiosity did not allow him to pass by the Hermetic science without giving it attention; in fact, he was the first German chemist of prominence and is ranked as a skilful practical chemist for the period in which he flourished. He became a Dominican friar in 1221, and from this time he was an instructor in philosophy, grammar, alchemy and natural history at Cologne, Paris, Hildesheim and Regensburg.

Michael Maier, a later writer on alchemy, states that Albert acquired the secret of the Philosopher's Stone from the disciples of St. Dominic and that he communicated it in turn to Thomas Aquinas. Maier further declares that for thirty years Albert employed his knowledge as an alchemist and astrologer to construct, from metals selected under proper planetary influences, an automaton having the power of speech. This was the curious Android, which was said to reply to every question proposed to it and which Thomas Aquinas destroyed under the impression that it was a diabolical machine.

Albert is also said to have suddenly reproduced the flowers and

softness of spring in the midst of winter for the entertainment of William II., King of the Romans, when the latter dined in the monastic house at Cologne. The views of Albert are in the main those of the Arabian school, altho he added many new chemical facts. He mentions alum, caustic alkali, red lead, arsenic, green vitriol, iron pyrites and liver of sulphur. He knew that arsenic renders copper white and he was familiar with the method of purifying the precious metals by lead. He found that sulphur attacks all the metals then known except gold and designated the cause of this combination by the term "affinitas."

In his "De Rebus Metallicis et Mineralibus," Albert states that he tested some gold and silver, said to have been manufactured by an alchemist, and which resisted seven fusions, but that the pretended metal was reduced to a scoria by an eighth fusion. He distinctly recognized the possibility of transmutation, however, when the operations were performed on the principles of nature; and considered that all metals are composed of an unctuous and subtle humidity, incorporated with a subtle and perfect matter—that is, the metals are all essentially identical, differing only in form. In one portion of his "De Alchymia," he asserts that gold is produced by the action of pure sulphur on pure mercury, by the permanent action of nature and after more or less time.

Thomas Aquinas (1225-1274), "the universal and the angelic doctor," was a Dominican friar and disciple of Albertus Magnus, and taught at Paris and Naples. Several works on alchemy have been ascribed to him. In one of these, the "Thesaurus Alchemiæ," he states that "the aim of the alchemist is to change imperfect metal into that which is perfect," and, moreover, asserts that such a transmutation is possible. The other works of this character attributed to him are "Secreta Alchymiæ Magnalia" and "De Esse et Essentia Mineralium." He wrote on the manufacture of artificial gems and some of the terms still in use by modern chemists occur in the supposititious writings of Aquinas, as, for example, the term "amalgam" for alloys containing mercury.

Roger Bacon (1214-1294), "the wonderful doctor," was born at Ilchester, in Somersetshire, England, and studied at Oxford and Paris. It is said that he studied history, learned the Oriental and Western languages, and gained a knowledge of jurisprudence and medicine, subjects to which little attention was given in his time; and, in order to prosecute his studies without interruption, he assumed the monastic life in the order of St. Francis. He employed his time not in the controversies of the day, but in researches into the properties of natural bodies, and by the aid of mathematical training and experiment he acquired a knowledge of mechanics, statics and optics. His success in physics and in the construction of automata kindled a

spirit of envy among the monks of his fraternity, and this led to the circulation of a report that he held converse with evil spirits, causing him to be imprisoned for ten years. He also knew how to use convex lenses for telescopic and microscopic purposes, and drew attention to the error which occasioned the Gregorian reformation in the calendar.

Bacon was familiar with many processes in chemistry, and doubtless would have produced great discoveries in this science had he not been drawn aside from the path of true investigation by the philosophical "ignis fatuus" which led the philosophers of this age to attempts at transmutation. He believed in the Philosopher's Stone and his views on the transmutation of metals may be illustrated by the following quotation from his "Speculum Secretorum":

> "To wish to transform one kind into the other, as to make silver out of lead, or gold out of copper, is as absurd as to pretend to create anything out of nothing. The true alchemists never held such a pretence. What is the real problem? The problem is, first, by means of art, to remove from the rough, earthy mineral a bright metallic substance, like lead, tin or copper. But that is only the first step toward perfection; and the chemist's work must not stop there, for, besides that, he must look for some means of getting the other metals, which are always present in the bowels of the earth in an adulterated condition. For example, the most perfect is gold, which one always finds in the native state. Gold is perfect because in it Nature finished her work. It is necessary, then, to imitate Nature, but here a grave difficulty presents itself. Nature does not count the cycles which she takes for her work, to which the term of life of a man is but as an hour. It is, then, important to find some means which will permit one to do in a little time that which Nature does in a very much longer time. It is this means which the alchemists call, indifferently, the elixir, the Philosopher's Stone, etc."

Bacon also stated that

> "With the help of Aristototle's 'Secret of Secrets,' experimental science has manufactured not only gold of twenty-four degrees, but of thirty, forty and onward according to pleasure."

The application of the study of alchemy to the extension of life was another subject of study with Roger Bacon, and he states that the operation by which the base metals are purged from the corrupt elements which they contain till they are exalted into gold and silver, is considered by every adept to be calculated to eliminate the corrupt

particles of the human body, so that the life of mortality may be extended for several centuries. The chemical investigations of Bacon have proved valuable, but the above mentioned alchemistic ideas seem incomprehensible to moderns when contrasted with his other views and knowledge. Gunpowder-like mixtures were within his knowledge, and, according to some, he names sulphur and saltpeter as two constituents, while the third constituent he denominates under the anagram "luru mone cap ubre." He probably derived this knowledge from some Arabic source. The Arabs were acquainted with gunpowder-like mixtures as early as 1280, and the knowledge of the propelling force of such mixtures came about between 1313 and 1325.

Bacon found that saltpeter could be purified by solution in water and crystallization; he subjected organic substances to dry distillation and observed that inflammable vapors were produced; and he called attention to the fact that air was necessary for the burning of a lamp. All these facts, together with many others, Roger Bacon learned by experiment, and he is to be regarded as the intellectual originator of experimental research. His important works are as follows: "Opus Majus," "De Secretis Operibus Artis et Naturæ," "Radix Mundi," "Speculum Secretorum," "Secretum Secretorum," "Breviarium de Dono Dei" and "Alchimia Major."

The alchemistic tendencies of the thirteenth century are distinctly reflected in the work of the two celebrated adepts, Arnaldus Villanovanus (Arnold de Villanova) and Raymundus Lullius, yet much uncertainty exists in regard to the life of the latter and to the works ascribed to him. Nevertheless both exercised no small influence on their generation and they were held in high esteem on account of their methods and labors. Arnaldus Villanovanus (1245-1310), whose birthplace is uncertain, studied medicine at Paris for twenty years, after which he traveled through Italy, visiting the various universities. He subsequently went to Spain and practiced as a physician in Barcelona, but learning that Peter d'Apono, a friend, had been seized by the Inquisition, he withdrew to Sicily, where he wrote his tracts on medicine under the patronage of Frederick II., King of Naples and Sicily.

Arnaldus was, however, charged with magical practices, and in 1317 the Inquisition of Tarragona condemned his books to be burned on account of the heretical sentiments they expressed. He was an adherent of the Arabian school, believing in the composite nature of the elements and in the transmutation of the metals, and his skill in Hermetic philosophy was recognized by his contemporaries, one of whom wrote, "In this time appeared Arnold de Villeneuve, a great theologian, a skilful physician and wise alchymist, who made gold, which he submitted to all proofs."

Arnaldus believed that quicksilver was the medicine of all the

metals, that sulphur was the cause of their imperfections, and that the Philosopher's Stone existed in all bodies. He was acquainted with oil of rosemary and oil of turpentine, and conducted distillations in a glazed earthen vessel with a glass top. He was probably the first to point out the poisonous nature of decaying flesh. He made external application of various mercurial compounds and understood some of the properties of alcohol. His knowledge of poisons was extensive. The principal works of Arnaldus are "Rosarius philosophorum," "Flos florum," "Antidotarium," "De Vinis" and "De Venenis."

Raymundus Lullius (1235-1315) was descended from an old and noble Catalonian family, and led a varied career. According to Waite, in his "Lives of the Alchymistical Philosophers," he "united the saint and the man of science, the philosopher and the preacher, the apostle and the itinerant lecturer, the dialectician and the martyr; in his youth he was a courtier and a man of pleasure; in mature age he was an ascetic who had discovered the universal science through a special revelation from God; after his death he was denounced as a heretic and then narrowly escaped beatification as a saint." He was probably initiated into the secrets of alchemy by Bacon and Arnaldus.

In all about 500 works have been ascribed to Raymundus, but there is very great uncertainty whether he is identical with the grammarian and dialectician of the same name, and, moreover, the errant life which he led could have afforded him few opportunities for the investigations involved in the search for the "magnum opus." Therefore it is supposed that many of his writings are spurious, altho three of his alchemical writings—the "Testamentum," "Codicillus seu Vademecum" and "Experimenta"—are regarded as genuine.

Among the other alchemists of this period were Jean de Meung, the monk Ferarius and Pope John XXII. The latter is claimed as an adept by the alchemists, but his orthodox biographers deny that he had any alchemistic inclinations. At his death in 1334, he left in his coffers eighteen million florins in gold and seven millions in jewels, and alchemists attribute these treasures to his skill in their science.

In the fourteenth and first half of the fifteenth centuries many alchemists were supposed to be in possession of the Philosopher's Stone. The prominent alchemists of this period were Nicholas Flamel, Peter Bono, Johannes de Rupecissa, Isaac of Holland and his son, Bernard Trevisan, John Fontaine, Sir George Ripley, Thomas Dalton and Thomas Norton.

Owing to the fact that alchemy was encouraged at many of the European courts at this time, many charlatans sprang up, pretending to be able to make gold without limit, and in some cases the frauds attempted were discovered. Nevertheless alchemy was not suppressed and it found especial protection at the court of Henry VI. of

England, nothwithstanding the fact that in 1404, by an Act of Parliament, it was forbidden to make gold or silver, as the preceding monarchs had had to pay heavily for their encouragement of the art. As early as 1344, Edward III. had coins struck from gold said to have been made in the Tower and later large quantities of counterfeit gold coins were manufactured. The alchemist Le Cor seduced Charles VII. of France into a similar experiment during a war with England, which only resulted in increasing the national debt. This counterfeiting caused much discredit to be attached to alchemy and the result was that this was extended to chemistry itself. However, the knowledge of chemical compounds and operations was enriched during this period by some valuable experimental observations, and toward the beginning of the sixteenth century chemical knowledge was greatly extended.

CHAPTER IV

THE LATER ALCHEMISTS

UNTIL lately the marked progress in chemical knowledge which occurred toward the end of the fifteenth century and at the beginning of the sixteenth century was always associated with the name of Basilius Valentinus, but the authenticity of the writings ascribed to him has become more and more questioned, and they are evidently spurious in parts. He seems to have been born at Mayence about 1394 and to have been a monk of the Benedictine order; but, altho numerous works have been printed in his name, no further particulars concerning his life have descended to posterity. The important works which appeared under his name are as follows: "Currus Triumphalis Antimonii," "De Microcosmo deque Magno Mundi Mysterio et Medicina Hominis," "Tractatus Chimico-Philosophicus de Rebus Naturalibus et Præternaturalibus metallorum et mineralium," "Practica, una cum duodecim Clavibus et Appendice," "De magno Lapide Antiquorum Sapientum" and "Testamentum ultimum." It is impossible to extract from these works the knowledge gained and possessed by the original author, but, as von Meyer states, "there can hardly be any doubt that a large number of facts were recorded by the writer who lived about a hundred years before the books were published, this being especially the case in the "Triumphal Car of Antimony," in which we possess what for a time was a marvelous description of an element and its compounds."

In this work the extraction of antimony from the sulphide found in nature is described and the properties of antimony are in part mentioned. Antimony was used in purifying gold and its compounds were applied medicinally. It would appear that Basil Valentine was the first to prepare hydrochloric acid by heating together copperas and common salt; and that he was acquainted with the rectification of the distillate obtained from beer and wine by means of potassium carbonate, the use of precipitation as a method of experimenting, and the employment of the spirit lamp in certain operations.

Judging from some passages in the works ascribed to him, Basil Valentine made the first attempts at qualitative analysis, for he proved that iron was present in certain hard tins, gold in Hungarian silver, silver in Mansfield copper and copper in Hungarian iron. The

language used in the works of Valentine is frequently obscured by mystical pictures and ideas, and, like others of his time, he often found it impossible to express his alchemistic thought in any language save that of far-fetched allegory.

The sixteenth century, a period of reformation, adventure and discovery, is characterized by the Paracelsists, who formed a transition from the alchemists of the Arabic school to the iatro-chemists. The latter had other objects of research than the alchemists, but as some of the Paracelsists and Medical Mystics were "hermetic philosophers," it is appropriate to refer to their alchemistic views here.

Paracelsus, the "Luther of Medicine," the "seer of Hohenheim," created a new school of alchemy. He considered that gold could be made by application of chemistry, but that the process is not to be compared with the method of producing gold by an exercise of the occult powers existing in the soul of man. On adopting this view, the Paracelsists with alchemistic tendencies abandoned experimental investigation and sought within themselves the great secret of alchemy.

Libavius, who criticized the mystical writings of the Paracelsists, nevertheless fully believed in the transmutation of the metals, and even van Helmont, the most distinguished of the iatro-chemists, went so far as to testify that he himself had affected the transmutation of mercury into gold. In his work, "De Vita Eterna," according to Waite, van Helmont makes the following declaration:

> "I have seen and I have touched the Philosopher's Stone more than once; the color of it was like saffron in powder, but heavy and shining like pounded glass. I had once given me the fourth part of a grain. I call a grain that which takes six hundred to make an ounce. I made projection therewith, wrapped in paper, upon eight ounces of quicksilver, heated in a crucible, and immediately all the quicksilver, having made a little noise, stopped and congealed into a yellow mass. Having melted it in a strong fire, I found within eleven grains of eight ounces of the most pure gold, so that a grain of this powder would have transmuted into very good gold nineteen thousand one hundred and fifty-six grains of quicksilver."

He states further that he performed a similar operation in public many times, and consequently believed in the certainty of the art, altho he did not possess the secret of making the transmuting agent. Other chemists of the sixteenth century, as Agricola and Sennert, were not avowed alchemists, yet they did not oppose views respecting the transmutation of metals. The last important iatro-chemist, Tachenius, alone contended against the ennobling of metals. His instructor in Leyden, Franz de la Boe, accepted the belief of his times in regard to transmutation.

In the reign of James I. of England reports were circulated that an artist, Butler, had performed several transmutations in London by means of a red powder secured from an Arabian alchemist, and later he is said to have accomplished wonderful cures with Hermetic medicine. Van Helmont attests these miracles, some of which he had the opportunity of witnessing.

After chemistry had assumed its proper position as a science in the Phlogistic Period and its study was neither obscured by attempts at transmutation nor limited to the preparation of medicines, many experimenters still remained convinced of the possibility of converting individual metals into one another. Altho alchemical work was kept secret to a great extent and was looked down upon, yet expressions of belief were far from being uncommon, even among such chemists as Robert Boyle, Johann Kunckel, Homberg, George Stahl and Hermann Boerhaave. In his old age, however, Stahl advised and warned against the pursuit of alchemy, and Boerhaave, after considerable experimental work, showed the falsity of many of the views held by the alchemists.

For example, the alchemists asserted that quicksilver could be fixed in a fireproof, metallic condition without the addition of any other substance, but Boerhaave disproved this by keeping quicksilver at a somewhat raised temperature in an open vessel for fifteen years without noting any change, and when he heated the quicksilver at a higher temperature in a closed vessel for six months no change was observed. Ernst von Meyer states in his "History of Chemistry" that "after his (Boerhaave's) time no notable exponent of chemistry—which had now attained to the rank of a science—spoke" in support of the alchemistic views, "but all the greater was the number of cheats and swindlers who cultivated the lucrative field of gold-making even during the eighteenth century. The conviction of the impossibility of transmutation, which was at that time establishing itself among scientific chemists, made its way but slowly into outer circles. Credulity and the hope of obtaining riches for nothing were the means of leading many into very doubtful paths, even so late as the end of the eighteenth century and the beginning of the nineteenth. The final echoes of the alchemistic problem which had for so long a period of time held the cultured of every nation in a state of tension and had even blinded eminent scientific men only appear to have died away during the last decades of the nineteenth century."

The statements of witnesses and conductors of alleged transmutations are often impressive and convincing, and such testimony is the strongest of the supposed evidence in favor of gold making. Probably the most interesting of such records is that contained in the "Golden Calf (the World's Idol)" of John Frederick Helvetius, an eminent Dutch physician, written in 1667. In this work, Hel-

vetius narrates the fact that he received from the "Artist Elias" a piece of the Philosopher's Stone the latter had in his possession, and that this piece—no larger than "a grain of rape seed"—transmuted six drams of lead into the finest gold. This gold was then taken to a silversmith, who first mixed four parts of silver with one part of the gold, "then he filed it, put aqua fortis to it, dissolved the silver, and let the gold precipitate to the bottom; the solution being poured off and the calx of gold washed with water, then reduced and melted, it appeared excellent gold, and instead of a loss in weight, we found the gold was increased, and had transmuted a scruple of the silver into gold by its abounding tincture." In the seventeenth century it appeared impossible to doubt such testimony; and at that time it was not known that the articles made from alchemistic gold were but worthless alloys, prepared for fraudulent purposes.

Among the other hermetic philosophers and adepts of the seventeenth and eighteenth centuries, may be mentioned: Jean d'Espagnet, author of a treatise on mystical alchemy; Alexander Sethon, who suffered from exposure of his "power"; Michael Sendivogius, who made gold by projection in the presence of Emperor Rudolph II. at Prague, and at Varsovia and Wurtemberg; Busardier, who left a powder when he died, one grain of which was used by Emperor Ferdinand III. for converting three pounds of mercury into gold; Eirenaeus Philalethes; Pierre Fabre; John Obereit; Lascaris, who is recorded as having changed mercury into gold and gold into silver; and Delisle. Alchemistic efforts were especially encouraged during this period at the courts of a large number of German princes, many of whom were amateur alchemists themselves and who expended large sums of money in fostering gold-making. The priests of trickery were, however, finally exposed as frauds and rogues, and a dire punishment was meted out to them, almost without exception.

It has been mentioned that the alchemistic ideas, with the transmutation of metals as their leading tenet, originated in Egypt, where they were first fostered by the initiates of the "Sacred Art"; and that the conversion of the sacred art of Egypt into alchemy resulted through contact with European thought and ecclesiastical mysticism. The Egyptian priests taught the unity of nature and asserted that a fundamental similarity existed between heavenly and terrestrial things; but alchemy, while its argument rested on a supposed familiarity with Nature's methods, and postulated an orderly and simple universe, applied moral conceptions to material phenomena and pursued a policy, rich in fantastic detail, dictated by fanciful conceptions.

The original and central aim of alchemy was the production of a

substance which was variously designated as the "Philosopher's Stone," "the one thing," "the essence," "the great elixir," "the great magisterium," "the red tincture," "the stone of wisdom," "the heavenly balm," "the divine water," "the virgin water," "the phœnix," "the lion," "the old dragon," "the basilisk," and "the carbuncle of the sun." This substance was supposed to have the power of transmuting base metals into gold; but other powers were attributed to it also, and the alchemist undoubtedly regarded it as "the soul of all things." After the eighth century, the Philosopher's Stone was reputed to possess the power of curing all diseases and was styled "the great panacea."

This belief in its powers came into existence gradually owing to the Western alchemists attaching too literal an interpretation to some of the Arabian descriptions of its powers; for instance, Geber termed the base metals invalids which he would cure (transmute) by means of the Philosopher's Stone. At a much later date (about 1600), it was claimed that the Philosopher's Stone could transform quartz into gems, change a thousand pearls into one pearl of great beauty, and render glass malleable. It was also said to possess the power of imparting moral culture and redemption from sin.

The descriptions of the "one thing" differ widely and the alchemists could describe it only in contraries. Some spoke of it as a red powder, others stated that it possessed a peach-blow color, and many affirmed that it was of a gray appearance. Paracelsus described it as a very stable, red substance, transparent as crystal, pliable as gum, and yet as fragile as glass. When pulverized, it was said to resemble saffron. Philalethes states, in his "Brief Guide to the Celestial Ruby":

> "The Philosopher's Stone is a certain heavenly, spiritual, penetrative, and fixed substance, which brings all metals to the perfection of gold or silver, according to the quality of the medicine, and that by natural methods, which yet in their effects transcend Nature. . . . Know, then, that it is called a stone, not because it is like a stone, but only because, by virtue of its fixed nature, it resists the action of fire as successfully as any stone. In species it is gold, more pure than the purest; it is fixed and incombustible like a stone, but its appearance is that of a very fine powder, impalpable to the touch, sweet to the taste, fragrant to the smell, in potency a most penetrative spirit apparently dry and yet unctuous, and easily capable of tinging a plate of metal."

The processes given for preparing the "Great Magisterium" are also numerous and varied. The methods whereby the agent is itself perfected, and the processes wherein the agent effects the perfecting of the base and unperfect things, were divided into ten or twelve

"Gates," or stages, by the alchemists. The prime requisite was the securing of the crude material to be employed. This was called the "materia prima cruda," "terra virginea," etc., and altho it was thought to occur in very large amounts, its identity was unknown and the procuring of this substance was considered to be the really difficult part of the undertaking.

From the "materia prima cruda" was to be obtained the "materia prima matura," a substance also known as the "mercurius philosophorum," or "azoth," to which was then to be added "auro philosophorum." This mixture was then digested at a low heat for some time without the presence of the air, in the "ovum philosophicum," to procure the "raven's head," or "caput corvi," a black substance which, through long digestion, became transformed into the "swan," a white body. The latter was then exposed to a higher temperature to produce the Philosopher's Stone. The various "Gates" were known as calcination, dissolution, conjunction, putrefaction, congelation, citation, sublimation, fermentation and exaltation.

The Alexandrians believed that the metals were alloys of varying compositions and, consequently, that the transformation of one metal into another was possible, either by means of the addition of other substances or the expulsion of some present; and the Western alchemists regarded all metals as compounds. For example, Arnaldus Villanovanus and Raymundus Lullius assumed mercury and sulphur as their constituents, and the latter asserted that every substance is composed of these two substances. Under the term "mercurius," or mercury, the alchemists saw the cause of metallic glance and malleability, while the term "sulphur" was used to express the idea of transmutability and also combustibility; and the various metals were regarded as compounds of these substances in different proportions.

For instance, gold, the most perfect metal, which Nature was thought to form slowly in the earth, was considered to be a compound of much mercury with only a small amount of sulphur. Therefore, considering that all other metals differed from gold only in the proportions in which mercury and sulphur were present, the alchemists sought for an agent whereby these proportions could be changed and gold produced. Introspection preceding observation gave rise to the alchemistic views of the universe and natural phenomena, and, to quote M. M. Pattison Muir, "the change from alchemy to chemistry is an admirable example of the change from a theory formed by looking inward, and then projected on the external facts, to a theory formed by studying facts, and then thinking about them."

Altho many of the theories of the alchemists were ridiculous and much unimportant material was accumulated by them, yet they un-

tiringly pursued their quest, their views were connected with their practice, and, as Muir observes, "there was a constant action and reaction between their general scheme of things and many branches of what we now call chemical manufactures." The result of this was that some progress, worthy of account, was made in the knowledge of applied chemistry during the alchemistic period.

Metallurgy was not the least of these. Three new metals—antimony, bismuth and zinc—were discovered in the second half of the Age of Alchemy and the knowledge of the properties of the metals already known was increased; but few alterations were made in the methods of extracting and purifying the metals. As might be expected, the greatest importance was attached to the treatment of gold and silver ores; and quite accurate balances came to be used as a result of the attention given to the yield of the noble metals. For a long time, gold was obtained in a pure condition just as it was in earlier times—that is, by the use of lead; but later it was ascertained that it could be purified by fusion with stibnite (antimony trisulfide), and in the time of Albertus Magnus it was found that gold and silver could be separated by treatment with nitric acid. Prior to this time, the cementation process of the ancients was employed for effecting the separation of the noble metals. Silver was extracted by fusion with lead, a method in use in Pliny's time.

Mercury was obtained by roasting its ores in furnaces and by distilling sublimate (mercuric chloride) mixed with caustic lime; it was used in extracting the noble metals, in gilding, and in alchemical research. Zinc and bismuth are mentioned in alchemical literature, and it would appear that zinc was used in the early medieval times; however, these metals were not used technically. Cobalt ore is also sometimes mentioned.

In the fifteenth century, copper was prepared by immersing plates of iron in solutions of bluestone (copper sulphate), but there are no important improvements to record in the methods of extracting and preparing iron, lead and tin. However, the various degrees of hardness and softness of iron were known at an early period, and the deportment of copper, iron, lead and tin when subjected to heat and to the action of acids was studied throughout the alchemistic period.

Ceramics advanced to no little degree. In ancient times glass had been colored by adding various oxides of metals to the fused mass, but in this age it was learned that the colors could be burned in—a decidedly important discovery. It was also found that the use of glazes containing lead and tin for earthenware vessels was advantageous for certain purposes.

Dyeing became better understood. Several important dyes were introduced during the alchemistic period. Orchilla, which was known in ancient Rome, was brought from the East about the thirteenth

century, and cochineal was introduced by the Arabians. Indigo also began to be used during this period. Alum was employed almost entirely as the mordant in dyeing.

Inorganic Compounds were more thoroughly studied. Nitric and sulphuric acids were obtained at an early date. The former was first prepared by the distillation of a mixture of saltpeter, bluestone and alum, but later it was found that it could be produced from saltpeter and sulphuric acid; and sulphuric acid was prepared by distilling a mixture of iron vitriol and pebbles, and by burning sulphur, after the addition of saltpeter, under a hood fitted with a side tube for the overflow of the acid produced. When sulphur is burned alone, a gas now known as sulphur dioxide is produced, and it is known that the water solution of this gas was often confounded with sulphuric acid. Geber prepared sulphuric acid by heating alum, but failed to study its properties other than finding that it was a powerful solvent. At a much later date, hydrochloric acid was prepared by heating common salt and green vitriol. This acid, which was known as "spiritus salis," was mixed with nitric acid to prepare "aqua regia," a strong solvent which the alchemists thought closely approximated to the "alkahest," or universal solvent.

The alchemists were acquainted with a large number of salts, of which it was thought that solubility in water was a general characteristic; hence, the term "sal" included a large number of substances and was widely distorted. The term "alkali" is first mentioned in the Latin writings ascribed to Geber, but, according to von Meyer, "one seldom meets in the alchemistic age with a strict distinction between potash and soda, or between their carbonates, while, on the other hand, preparations of carbonate of potash obtained in different ways were regarded as dissimilar products. The distinction drawn by Abu Mansur between 'Natrun'—*i.e.*, the soda found in Nature as a mineral deposit—and 'Qualia,' the alkali from the ashes of land plants, is, however, very noteworthy. These names have been perpetuated in the German words 'natron' and 'kali.'" The solvent power of the lyes obtained from the carbonates of potash and soda by the addition of lime, was made use of by the alchemists.

Among the salts known to the alchemists were alum, which was prepared from alum shale and widely used; iron and copper vitriols; saltpeter, salmiac and carbonate of ammonia. Saltpeter (potassium nitrate) was probably used in early times in the manufacture of fireworks; it was known in various periods of this age as "sal petrosum," "sal nitri" and "nitrum." Salmiac, "sal ammoniacum," chloride of ammonia, was originally prepared from dung, altho some of the naturally occurring product of volcanic origin was used. Carbonate of ammonia was prepared by the chemists of the thirteenth

century and was known to them as "spiritus urinæ"; later it was obtained from salmiac and alkali carbonate.

Other inorganic compounds known to the alchemists were nitrate of silver, chloride of silver, mercuric oxide, mercuric chloride, basic mercuric sulphate, mercuric nitrate, zinc oxide, zinc sulphate, antimony trichloride, basic chloride of antimony, antimony trioxide, potassium antimoniate, arsenious acid, peroxide of iron, oxide of copper and the lead oxides. As before mentioned, the alchemists knew that gold disolved in "aqua regia"; this solution, "aurum potabile," was thought to possess wonderful medicinal effects. They also knew that silver could be precipitated from a silver nitrate solution by the use of mercury or copper.

The preparation of antimony from the sulphide by fusion with iron, is described in several of the works ascribed to Basil Valentine. It is mentioned in these works that antimony does not possess the properties of a metal in full degree, and that it is a variety of lead. In the fifteenth century, antimony was used in certain alloys, and the compounds of it then known were used in medicine. Arsenic was prepared in the thirteenth century by the Western alchemists, who considered that it was a "bastard metal." Arsenious acid was prepared as early as the tenth century, by roasting realgar, and was called "white arsenic." At a much later period, about the close of the Medieval Age, it was observed that arsenious acid occurs in the fumes from pyrites' furnaces.

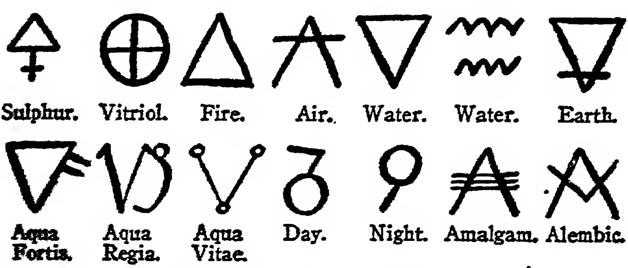
Mention has been made of some sulphur compounds, the sulphides of mercury (cinnabar) and antimony (stibnite) among others, which were found to be valuable materials for the production of sulphur and other bodies. These were grouped together as forming a particular variety of compounds, under the name of "marcasitæ" (Albertus Magnus), zinc blende, galena (lead sulphide), and iron and copper pyrites being included among them. The peculiarity which these substances had in common, that of giving off a product of such characteristic odor as sulphurous acid, when roasted, may have formed the main reason for assigning them to one group. It should be remembered, however, that the production of several metallic sulphides from their components had been observed (*e.g.*, the formation of cinnabar from quicksilver and sulphur), and this may be supposed to have contributed materially to a knowledge of their composition. Realgar and orpiment were known to the Arabian physicians.

The alchemists were fond of using the names of animals as symbols of certain mineral substances, and of representing operations in the laboratory by what may be called animal allegories. The "yellow lion" was the alchemical symbol of yellow sulphides, the "red lion"

was synonymous with cinnabar, and the "green lion" meant salts of iron and of copper. Black sulphides were called "eagles," and sometimes "crows." When black sulphide of mercury is strongly heated, a red sublimate is obtained, which has the same composition as the black compound; if the temperature is not kept very high, little of the red sulphide is produced; the alchemists directed to urge the fire, "else the black crows will go back to the nest."

Organic Compounds were also examined and their properties recorded. Notwithstanding the fact that the alchemists originally paid more attention to the properties of mineral bodies rather than to those of organic bodies, yet the study of the action of heat upon bodies when air is excluded and improvements in methods of distillation, led to the investigation, in a crude manner, of the products of distillation and eventually to the discovery of definite organic compounds. Among the few organic preparations known to the alchemists, spirit of wine takes a prominent place. This compound was formerly designated by very different names; for instance, Marcus Graecus (eighth century) calls it "aqua ardens," the Latin translators of Geber's works refer to it as "aqua vitæ," and others mention it as "aqua vitis," "mercurius vegetabilis," "spiritus vivus" and "consolatio ultima corporus humani." The term "spiritus vini" first occurs in the writings ascribed to Basil Valentine, and the name "alcohol" was first used by Libavius at the end of the sixteenth century.

The symbols used to denote the metals have been referred to; among other signs employed instead of writing the names of substances, were the following:



SOME ALCHEMICAL SYMBOLS.

The Alexandrians employed two vessels in conducting a distillation, one for evaporating the liquid and the other for condensing the vapor, and this improvement resulted in the simplification of the method of manufacturing spirit of wine, and an extension of its

importance in medicine and alchemy. The preparation of concentrated spirit of wine by repeated distillation and by rectification over dry carbonate of potash was described by Raymundus Lullius, who also examined the action of sulphuric acid upon spirit of wine. Spirits were generally dehydrated by rectifying at a low temperature, however, and in order to condense the vapors completely they were passed through long condensing tubes, often of an extraordinary form.

At the close of the Middle Ages, the alchemists were acquainted with several ethers, which they prepared in an impure state by the action of acids on spirit of wine. One of the alchemical writers speaks of a spirit prepared in this way which has a "subtle, penetrating, pleasant taste, and an agreeable smell." This probably referred to ethyl oxide, or ethyl ether, a compound prepared by various chemists in the sixteenth and seventeenth centuries.

The belief in the transmutability of metals was dismissed from chemistry when Lavoisier established the important generalization of the new chemistry, namely, that matter may be changed, but neither destroyed nor created (1770). Nevertheless, many have applied themselves to attempts at converting the bountiful metals into the agreed standard of exchange, but these experimenters have been for the most part men of limited chemical knowledge and experience, and, to quote Charles Baskerville, "a careful analysis of the motives actuating and methods pursued presents merely an inferior picture of the perfected practises we are gradually learning of as obtaining in that circle termed 'high finance.'" The alchemical literature of the nineteenth century is quite extensive, but is, in general, cabalistic and teeming with credulity, misconception, and misinformation.

At the present time, there is a strong inclination among chemists toward a belief in the mutual convertibility of chemically similar elements. This view is based on the supposition that all the chemical elements are combinations of different qualities of one primal element and on the peculiar conduct of certain recently discovered elements; in fact, the belief in the transmutation of atoms is in close agreement with the present theories of atomic disintegration, but this is based upon new discoveries and on correctly interpreted chemical problems, and not upon false deduction and experiment. It is, therefore, not to be confused with the earlier views, for even if the hypothetical primal element should be isolated, one aim of alchemy would be fulfilled, but the fulfillment would not be that whereof the alchemistical philosophers taught and dreamed.

CHAPTER V

THE PERIOD OF MEDICAL MYSTICISM

The sixteenth century, one of epoch-making discovery, witnessed the differentiation of Chemistry from Alchemy. Up to this time traditional belief had dominated every branch of science and scientific inquiry had been pursued almost solely in the cloister; but now the great universities of Oxford, Heidelberg, and others in France and Italy, were beginning to make their influence felt, and the sciences found a foothold in these institutions. Then, too, these seats of learning favored the free exchange of thought, and the introduction of the art of printing resulted in the quick and wide dissemination of ideas. Consequently, the capacity for reflection and criticism spread, and the boundaries of human knowledge were enlarged.

A further aid to the development of the natural sciences was supplied by certain modern eclectic philosophers who perceived the defects and errors of ancient lore and philosophy, and burst the enclosures of authority by attempting innovations in philosophy. The inductive method was found to be of especial value in combating and controverting medieval belief, and by its means the experimental sciences came into existence.

It was believed that Chemistry should serve the interests of Medicine, and therefore, there was a strong tendency toward a concatenation of the two. Medicine was, to a certain extent, regarded as a division of Applied Chemistry, and then it began to be viewed as the true end of Chemistry. The chemist was to discover, prepare and investigate medicines—duties which resulted in the carrying out of many careful researches and in the discovery of new compounds, while the physician was to study their action on the human economy. This fusion resulted in the birth of Organic Chemistry; and the application of men belonging to a learned profession to the problems offered by chemical phenomena, enriched both Medicine and Chemistry. This increase in knowledge gradually led to definite ideas, and the Iatro-Chemical Period thus formed a period of extension for Chemistry.

In the first half of the sixteenth century, a Suabian physician, Philippus Aureolus Paracelsus Theophrastus Bombastus von Hohen-

heim, better known as Paracelsus, a name which has always carried with it a mysterious suggestion of power, liberated Chemistry from the yoke of Alchemy and joined it with Medicine. He accomplished this during a period of ecclesiastical and national reformation—when Luther and Calvin were combating against superstition, when Copernicus was remodeling astronomy—and the changes he wrought, through his originality of thought and teaching, and freedom and vigor of expression, well entitled him to the appellation some have seen fit to give him, the "Luther of Medicine."

Paracelsus was born at Einsiedeln, Switzerland, on November 10th, 1493, and died in the hospital of St. Sebastian, in Salzburg in the Tyrol, in 1541. The character and ability of Paracelsus have been rated high by some, and extolled and abused by others, even his disciples.

One writer says of him: "He lived like a pig, looked like a drover, found his greatest enjoyment in the company of the most dissolute and lowest rabble, and throughout his glorious life he was generally drunk." It is true that his life offered a strong contrast to his mentality, but he was a man of noble character and intentions, a Christian humanist and ambulatory theosophist, who hoped to inspire mankind with a love of conscientiousness and veracity and to restore the suffering to health.

Paracelsus was active as a teacher, physician and writer, and over a hundred books have been attributed to him. These works cover many subjects—chemistry, medicine, astrology, botany, etc.—but it has lately been shown that much of the subject matter was not really his. The chemical knowledge and medical views of Paracelsus are best seen in the following works: "De Tinctura Physicorum," "Archidoxa," "Paragranum," "Paramirum," "De morbis ex Tartaro Oriundis" and "Grosse Wundarznei." Two other of his well known works are "Das guldin Flüss" and "Testamentum Theophrasti Paracelsi." An excellent collection of various editions of the works of Paracelsus, together with many commentaries and translations, is now preserved in the Homeopathic Medical College of Philadelphia.

Paracelsus taught that "the object of chemistry is not to make gold, but to prepare medicines," and he considered that the operations which occur in the human body are chemical ones and that the state of health is dependent upon the composition of the organs and the juices they secrete. Medicine, Paracelsus asserted, rests upon four pillars, chemistry, philosophy, astronomy, and virtue. Organic bodies were composed of mercury, sulphur and salt, which corresponded to the physical "phenomena of volatilization, combustibility and solidification," but which were related in a higher sense to spirit, soul and body; and the increase and decrease of these principles from their normal amount caused illnesses.

For example, he states that an increase of mercury produces

paralysis, that an increase of salt gives rise to diarrhea, and that gout results from the elimination of the sulphur of the body. Paracelsus maintained that each disease must be antagonized by specific medicines ("arcana"), and that the preparation of these remedies was the aim of chemistry. In inaugurating this method of combating disease, he employed many chemical preparations, among which were sugar of lead (lead acetate), corrosive sublimate (mercuric chloride), copper vitriol (copper sulphate), lapis infernalis (silver nitrate), and many antimony compounds.

In addition, he was the first to use oil of vitriol sweetened by spirit of wine, iron saffron and iron tinctures; and introduced improved methods of preparing various essences and extracts by means of spirit of wine. These additions to the medical treasury instigated apothecaries and physicians to engage in the study of chemistry; for the preparation of new medicines required a certain familiarity with chemical facts, and before the advent of Paracelsus, the apothecary had been a mere herbalist and storekeeper. It may be said, therefore, that pharmacy began here, and that pharmacy as a distinct profession and subject of study was largely founded by Paracelsus.

There seems no doubt that Paracelsus discovered many facts which became of importance in chemistry. He distinguished metals from substances which had been classed with metals; his criterion of a metal was ductility, and he was therefore led to separate the metals from the half-metals—a foundation for a classification of the metals which lasted for many generations. He obtained the inflammable gas we now call hydrogen by the reaction between iron filings and sulphuric acid, tho it could not be said to be a discovery in the sense of preparing and identifying the gas. The work he did upon the preparation and application of various inorganic and organic compounds, led to an extension of the knowledge of chemical preparations.

Andreas Libau (Libavius) was born at Halle, and there studied medicine and practiced as a physician. He also acted as head of the "Latin School" at Rothenburg from 1591 to 1607, and later became director of the gymnasium at Coburg, where he died in 1616. Libavius had a wide knowledge of chemistry and made many valuable chemical discoveries. From tin he obtained its tetrachloride, by distilling it with sublimate; and to him belongs the merit of simplifying the method of preparing sulphuric acid, and of showing that the acid obtained in many ways—from alum, sulphate of iron, or sulphur and nitric acid—was the same substance (oil of vitriol). He also discovered sulphate of ammonia, and investigated the acetates of lead. He vigorously combated the defects in the doctrines of Paracelsus, and did much to indicate the meaningless nature and

obscurity of the mystical and sophistic writings of the Paracelsists.

Libavius wrote the first text-book on chemistry, which put, clearly and in order, all the most important facts and theories of the science at the date of publication (1595); this work, which was published under the title "Alchemia e dispersis passim optimorum actorum . . . collecta, adhibitisque ratione et experientia quanta potuit esse methodo accurata explicata et in intergrum corpus redacta," was frequently reprinted and was held in high esteem for a long time. His other writings appeared under the title, "Opera Omnia Medico-chymica" shortly before his death.

Libavius possessed a thoro general education and a sound judgment, yet he believed in many of the tenets of alchemy. This was mainly due, however, to the predilection of the period in which he lived, and did not prevent Libavius from serving the interests of chemistry to good purpose. It is important to mention that he made efforts to establish large and well-fitted chemical laboratories.

Paracelsus and his followers had turned chemistry into new lines, and the finest talent was enlisted in the ranks of the iatro-chemists, or medico-chemists, to whose work Paracelsus had given such impetus. The most distinguished of these iatro-chemists was Johann Baptist van Helmont, a celebrated physician, born at Brussels in 1577. At an unusually early age van Helmont applied himself to the study of philosophy and theology, and, to quote from an autobiographical fragment which he left (Brande), "In 1594, being then seventeen years of age, I finished my courses of philosophy, but upon seeing none admitted to examinations at Louvain who were not in a gown and hood, as tho the garment made the man, I was struck with the mockery of taking degrees in arts.

"I therefore thought it more profitable, seriously and conscientiously, to examine myself; and then I perceived that I really knew nothing, or, at least, nothing that was worth knowing. I had, in fact, merely to talk and to wrangle, and therefore refused the title of Master of Arts, finding that nothing was sound, nothing true, and unwilling to be declared master of the seven arts, when my conscience told me I knew not one. The Jesuits, who then taught philosophy at Louvain, expounded to me the disquisitions and secrets of magic, but these were empty and unprofitable conceits; and instead of grain, I reaped stubble. In moral philosophy, when I expected to grasp the quintessence of truth, the empty and swollen bubble snapped in my hands.

"I then turned my thoughts to medicine, and having seriously read Galen and Hippocrates, noted all that seemed certain and incontrovertible; but was dismayed upon revising my notes, when I found that the pains I had bestowed, and the years I had spent, were al-

together fruitless; but I learned at least the emptiness of books and formal discourses and promises of the schools. I went abroad and there I found the same sluggishness in study, the same blind obedience to the doctrine of their forefathers, the same deep-rooted ignorance." He therefore concluded that medical knowledge was not to be obtained from the writings of men or from human industry.

About this time he learned, from a chemist, the practical operations of the chemical art, and devoted himself with great zeal and perseverance to this pursuit, in hopes of finding in a chemical laboratory that knowledge which he had in vain sought for from books. The medical skill, which he by this means acquired, he emloyed in the service of the poor, and, in addition, he enriched chemistry by a great number of valuable observations. He died in Brussels in 1644.

Van Helmont possessed ready talents, read much, and by the aid of experiment, improved both chemistry and medicine; but his vanity led him into empirical pretensions and he had an intense inclination toward the supernatural—the result of his mystical studies and application to theology, especially to the pious writings of Thomas-a-Kempis and John Tauler. Thus did he who possessed powers of observation and perception unapproached before his time by any other observer, give expression to fantastic views upon the elements and vigorously defend the transmutation of the base metals into gold. He thought that wisdom is to be obtained only by humility and prayer, and believed that he had once seen his soul as a brightly shining crystal.

He was convinced that dirty linen packed in a vessel with flour would in time produce mice, and that a toad's bones applied to an offending part was a certain anodyne. He boasted that he possessed a fluid, the "alcahest," which was capable of penetrating into bodies, producing an entire separation and transmutation of their component parts. No one, not even his son, saw this wonderful fluid, and its possession was a secret van Helmont cautiously guarded.

Van Helmont looked upon water as the chief constituent of all matter, and brought forward many arguments in support of his theory from the animal and vegetable world. That water was present in organic bodies he concluded from the fact of invariably procuring it as a product of their combustion. He believed that he contributed a strong proof of this by the following experiment: He took an earthen vessel of large dimensions, and filled it with two hundred pounds of dry earth, in which he planted a willow weighing five pounds. This was then duly watered with rain and distilled water for five years, at the end of which time he pulled up the willow and found that it weighed one hundred and sixty-nine pounds and three ounces. Moreover, the earth had decreased two ounces in weight.

He therefore concluded that one hundred and sixty-four pounds of root, leaves, etc., had been produced from water alone, and that it was the only nutriment of plants. Fish, he asserted, live on water, and nevertheless, they contain all the peculiar animal substances; the latter are therefore produced from water.

Basing his belief on such imaginary proofs as these, van Helmont was convinced of the transformation of water into earthly matter. With respect to his views concerning the four Aristotelian elements, he denied altogether that fire could be of a material nature, but it is uncertain whether he regarded air as an element or not. His conception of the elements also differed from those of Basil Valentine and Paracelsus, for mercury, sulphur and salt were not to be detected in the human body.

Until the time of van Helmont little was known concerning gases. Pliny had spoken of "spiritus," which possessed properties differing from those of ordinary air; and of terrestrial emanations, some of which were combustible, others unendurable. But even Basil Valentine looked upon all such as common airs with differing impurities. Paracelsus had observed the evolution of gas when sulphuric acid is poured on iron, but this had appealed to him only as a mere expulsion of air. Van Helmont, however, changed the whole aspect of the question and proved himself an investigator of the first rank when he opened out a new field for chemistry by his researches on gases. In his writings the word "gas" occurs for the first time, a word he probably derived from the German "gäscht," the foam which appears during the process of fermentation; and by this generic name he classed all such emanations as could not be brought into the liquid state. For example, the gases now known as hydrogen, carbonic acid, and sulphurous acid were distinguished by van Helmont from vapors, in so far that the latter were condensed to liquids upon cooling, while the former were not.

The views of van Helmont on the composition of substances also were far in advance of any of his predecessors, and he recognized much more clearly than his contemporaries the unalterability of matter in many instances. Van Helmont further showed that the same substance continued to exist in many of its compounds, as, for example, silver in its salts; and demonstrated by quantitative experiment that if one body combines with another and is then precipitated, the weight so obtained is equal to that originally taken; *e.g.*, he found that silica, when fused to a glass with potash and again precipitated by the addition of an acid, lost nothing in weight. He had therefore clearly grasped the fundamental idea of the theory of the conservatism of matter in certain cases.

The footsteps of this iatro-chemist were closely followed by his son, Francis Helmont, whose "Paradoxical Dissertations" are a mass

of medical and theological paradoxes, scarcely to be paralleled in the history of literature. He did a service, however, by publishing the collected works of his father in 1648. These works, which appeared under the title "Ortus Medicinæ vel Opera et Opuscula Omnia," were translated into German, English and French, and passed through three Latin editions.

Other influential men of this time were François de la Boe Sylvius, Otto Trachenius and Thomas Willis. Sylvius was born at Hanau in 1614, but his life was mainly spent in Holland. In learning and culture he far surpassed most of his contemporaries, and he ably filled the chair of medicine in Leyden until his death in 1672. Sylvius directed all his efforts to showing that the physiological and pathological processes occurring in the human body were purely of a chemical nature, and his views were in the main those of Van Helmont, with the spiritualistic element omitted. He did not hesitate to prescribe preparations of antimony and mercury, nitrate of silver, mercuric chloride, and zinc vitriol for internal use in medicine. His "Opera omnia" were published in Paris in 1671.

Otto Tachenius, a devoted pupil and follower of Sylvius, was born at Herford in Westphalia and practised as a physician at Venice in the middle of the seventeenth century. He was the last iatrochemist of importance who adhered to the doctrines of Sylvius, and was an investigator of note. He made some valuable contributions to the knowledge of the composition of chemical substances, originating the first pointed definition of the term "salt," as a compound of an acid and an alkali, and studying the proportions by weight in which substances react chemically. One of his important observations is that in which he noted the increase in weight which takes place when lead is transformed into its oxide. Among the writings of Tachenius, the following two English translations are best known: "Clavis to the ancient Hippocratical Physick or Medicine made by manual experience in the very fountains of nature, whereby through fire and water, in a method unheard of before, the occult mysteries of nature and art are unlocked and clearly explained by a compendious way of operation" (1677); and "Hyppocrates Chymicus" (1677).

In 1659 appeared the "Diatribe de Fermentation" of the English chemist Willis, who held that fermentation was a decomposition brought about by communication of a vibratory motion to the particles of dust, and the resulting separation of their loosely combined components. This theory was developed by Stahl forty years later.

The iatro-chemical doctrines contributed much to the general advancement of the science of chemistry, but two mistakes were made by the iatro-chemists: they endeavored to explain, on chemical principles, all the changes and processes occurring in the body—an attempt

which was futile for the chemistry of that day; and, secondly, they set too narrow a limit for chemistry, which was not destined to remain in a subordinate position. Consequently, their medico-chemical ideas were upset after the middle of the seventeenth century, altho the tenet of the Phlogistic Period—the phlogistic hypothesis, which predominated during most of the eighteenth century—was indicated by many of the iatro-chemists.

No mention has been made thus far of those distinguished technical chemists—Georgius Agricola, Bernard Palissy and Johann Glauber—who promoted applied chemistry during the iatro-chemical age. This was made necessary, since they worked independently of the main iatro-chemical current and, in general, only fostered chemistry in its application to industries.

Contemporaneous with Paracelsus, but forming a strong contrast to him, was the true investigator, Georgius Agricola, who was born at Glauchau, near Meissen, in 1494, and died while mayor of Chemnitz in 1555. Agricola was a noted physician, but devoted himself more particularly to the study of mineralogy and metallurgy, writing little on medical subjects and not troubling himself about the storm over the revolution of Paracelsus. His works, which are indispensable to the history of metallurgy and mineralogy, are characterized by clearness and intelligibility; they are as follows: "De re metallica libri XII, quibus officia, instrumenta, machinæ, ac omnia denique ad metallicam spectantia non modo luculentissime describuntur, sed et per effigies suis locis insertas, adjunctis Latinis Germanicisque appellationibus, ob oculos ponuntur, ut clarius tradi non possint" (1546); "De ortu et causis subterraneorum—de natura eorum quæ effluunt ex terra—de natura fossilium—de veteribus et novis metallis—Bermannus, sive de re metallica dialogus" (1558), and "De mensuris et ponderibus, . . . de precio metallorum et monetis" (1580). It was through these writings that the important metallurgical operations first became generally known; Agricola was also among the first to indicate a method by means of which it was possible to estimate approximately the amount of metal in an ore, and to explain intelligibly the manufacture of various preparations of industrial importance.

Vanuccio Biringucci, author of a work on metallurgy entitled "Pirotecnica" (1540), in which various technical processes are described, like Agricola, held aloof from the discussion of the iatro-chemical questions current in his time. He gave directions for preparing ultramarine, distinguishing it from copper azure.

Bernard Palissy busied himself in the domain of the ceramic art, and succeeded in affixing durable enamels on earthenware vessels, especially on those of faience pottery. His observations on enamels, on the burning-in of colors, and on the use of various clays for pot-

tery, are embodied in his work, "L'Art de Terre." His works are clearly written, and show that he contributed to the founding of agricultural chemistry and mineralogy, and that he combated every speculation not based upon observation and experiment; among these are his "Discours admirables de la nature des eaux et fontaines, tants naturelles qu' artificielles; des metaux, des sels et salines, des pierres, des terres, du feu et des emaux; avec plusieurs autres excellents secrets des choses naturelles" (1580); and the "Moyen de devenir riche et la maniere veritable par laquelle tous les hommes de la France pourront apprendre a multiplier et augmenter leurs thresors et possessions" (1636). Along with Agricola, Palissy was the chief exponent of experimental chemistry in his time.

The next name of importance is that of Johann Rudolf Glauber, who was born in Franken, Bavaria, in 1604, and died at Amsterdam in 1668, and who still shares a somewhat hazy popular fame as the discoverer of "Glauber's salt" (sodium sulphate). This compound, which is mentioned in his "De Natura Salium," published in 1658, was obtained from the residue left in the preparation of hydrochloric acid, and, under the name "sal mirable," was prized highly by physicians.

In his "Proserpine: or, the Goddess of Riches," Part III, Glauber details "the fundamental process, how to make good gold out of silver, with profit, and how to separate good gold and silver out of iron, tin, copper, and lead."

Notwithstanding his adherence to mysticism, Glauber enriched chemistry in an eminent degree by his discoveries. In attacking the question of the composition of bodies, he commenced by considering the conditions under which certain salts were produced, and the products of their mutual decomposition. Instead of preparing the chlorides of metals as heretofore, by heating the metal with sublimate (mercuric chloride), he treated the metal directly with hydrochloric acid, and concluded that the salt produced was merely a solution of the metal in the acid. This was a convincing blow to the time-honored idea that the mercury of the sublimate had entered into the composition of the chlorides obtained.

Moreover, Glauber taught how to prepare hydrochloric acid from rock salt and oil of vitriol, and also fuming nitric acid from saltpeter and white arsenic. The preparation of hydrochloric acid, or "spirit of salt," is described in the first section of the second part of the "Miraculum Mundi." Here also is given the method of obtaining "sal mirable," the discovery of which first appeared in his "De Natura Salium." To the discussion of the "spirit of salt," Glauber adds: "Plainly after the very same manner as we have taught spirit of salt to be prepared, so may also be made 'Aqua fortis' (nitric acid). . . . Instead of salt take niter, and you will have 'Aqua fortis.'"

For a long time afterwards the acid thus obtained (fuming nitric acid) was known as "spiritus nitri fumans Glauberi."

The combination of acids with metals or alkalis was attributed by Glauber to a certain associative tendency, which he termed "Gemeinschaft." He never employed the term "affinity," altho, as mentioned before, it was already the property of chemical literature. In Glauber's works we find a clear description of the preparation of sulphate of ammonia, formerly known as "sal ammoniacum secretum Glauberi," and the discovery of nitrate of ammonia, "nitrum flammans." He was also the first to prepare chlorides of arsenic, and ferric and plumbic chlorides, and to him is due a clearer knowledge of the chemistry of antimoniate of potash and other antimony compounds. He prepared impure zinc chloride by heating calamine strongly with hydrochloric acid; proved that copper sulphate, blue vitriol, is produced by boiling copper with oil of vitriol; and he was the first to mention a case of what is called double decomposition. His observations on the latter are of interest; to quote from one of his treatises, "Aqua regia which has taken gold into solution kills the salt of tartar (potash) of the liquor of flints (silicate of potash) in such a way as to cause it to abandon the silica, and in exchange the salt of tartar paralyzes the action of the aqua regia in such a way as to make it let go the gold which it had dissolved. It is thus that the silica and gold are both deprived of their solvents. The precipitate is composed, then, at the same time of gold and of silica, the weights of which together represent that of the gold and of the silica originally taken."

With Glauber and Tachenius the period of Medical Mysticism closes. Both of them advanced chemistry by valuable observations, and in many of their chemical ideas and also in point of time, they really belong to the next, the Phlogistic, Period. The iatro-chemists had preserved a real science throughout a troublous and Philistine period, while their often fantastic speculations had caused no inconsiderable increase in the knowledge of chemical preparations. However, the advance in the knowledge of the composition of substances and in the observation of reactions first became pronounced toward the close of the Period.

In the works of Agricola, Biringucci, Cæsalpino, Glauber and Palissy, stress is laid upon accurate description of technical operations, and it is from these works that knowledge accrues of the progress made in technical chemistry during the Iatro-chemical Period.

With regard to the extension of metallurgical knowledge, it is to be expected that the iatro-chemists were more interested in the salts prepared from metals than in the latter themselves, as there was always the possibility of chemical preparations proving of value in

medicine. Nevertheless, especially in the works of Agricola, referred to before, it is found that a knowledge of the individual metals and of metallurgical operations became extended in the sixteenth century, as a result of the publication of what had hitherto been kept secret. The methods of obtaining iron became known through the works of Agricola, and he was the first to describe the production of steel by the puddling process. It is interesting to note that steel was looked upon as a very pure iron. Of the other metals, the separation of gold and silver by means of nitric acid, and the amalgamation process became generally known; tin was employed in the sixteenth century for tinning iron; and altho zinc and bismuth were often confused with antimony, yet a better knowledge of them was acquired, and the tutty from zinc ores was employed for making brass.

Considerable interest was evinced in the distillation of liquors during this Period, and numerous works upon this subject appeared; among these were the following: Hieronymus Saler's "Liber de arte distillandi de compositis" (1500, 1512, 1527); John French's "The Art of Distillation" (1651); and Elsholtz's "Distillation curiosa seu ratio ducendi liquores coloratos per alembicum" (1674), Many improvements were made both in distilling apparatus and in the methods of distillation, and the distillation of brandy became an industry.

The word distillation up to the end of the fourteenth century meant the separation of the more light or subtle parts of anything from the more heavy or gross by a process of dropping. Thus Geber and others included the filtration of a liquid as a variety of distillation. The Latin word "distillo" applies to a dropping liquid, but such employment of the term does not appear after the fourteenth century in chemical works, altho the older use of "distil" is still found in ordinary writings, especially in poetry, and occurs in Fielding and Shakespeare. The process of distillation was classified in various ways; for instance, according to the source and mode of application of the heat, the shape of the alembic or distillatory vessel, and the direction impressed on the vapor upward or downward ("distillatio ascensum vel descensum").

The heat was applied in the form of the direct heat of à fire, or the heat conveyed through water or through sand, or the direct heat of the sun. Porta, about 1585, employed concave mirrors to concentrate the sun's rays (Fairley). Repeated distillation was often prescribed, as the purity of the distillate was sought to be increased by each distillation up to the fifth distillate, which was termed the "quintessence." An alcoholic distillate obtained in this way from selected wine was considered to possess great medicinal value.

During the sixteenth and seventeenth centuries the distillation of

fermented alcoholic liquids became subject to State supervision in many European countries. In Ireland, where it has been shown that the distillation of a spirit from fermented barley was practiced in 1170, up to 1556 the distillation of spirits was carried on without license or taxation. In the reign of Henry VIII, distilleries were established in Pembroke by Irish settlers, and it is considered likely that the soldiers of Henry II, 300 years previous, brought back with them the knowledge of whisky, or "uisque-beatha." The manufacture of "aqua vitæ" from malt appears to have been common in Scotland and England in 1494, and, in the middle of the seventeenth century, the manufacture of spirits was made a source of revenue by excise duties on the amount manufactured. In the Tudor and Stuart period, licenses had been required to use stills.

The knowledge of chemical compounds, especially the preparation of inorganic compounds, showed decided improvements; and the beginnings of qualitative analysis are to be sought for in this Period, in so far that conclusions concerning the presence of one or another constituent were deduced from the appearance and behavior of precipitates and salts which crystallized out from solutions. Glauber designed several forms of furnaces and casting vessels which were found to be useful in the preparation and investigation of a number of inorganic substances.

As a result of the attention paid to the products of vegetable and animal assimilation, organic compounds became known in rapidly increasing numbers, but the composition of these bodies remained quite undiscernible. It is worthy of note that many of the iatro-chemists assumed that "oil or fat contains a hidden acid," basing their conclusion on the old observation that fats were acted upon and changed by alkalies.

CHAPTER VI

THE PERIOD OF GENERALIZATION

HERETOFORE the inducements to a study of chemical phenomena had been successively a belief in the possibility of transmutation, and a conviction in the potency of heroic medicines prepared in the chemical laboratory. But from the middle of the seventeenth century onward another aim is manifest in the works of the masters; for, from the time of Boyle forward, the great end of chemistry was recognized as being the discovery of new chemical facts, with the object of arriving at the truth alone, and, thanks to the spirit of true investigation which had begun to extend itself to chemistry and the effect of the inductive method of Francis Bacon, chemistry assumed its proper place as a science.

As an approach is made to modern times, it becomes more difficult to define historically the successive phases of chemistry. The learned societies which were founded in the second half of the seventeenth and beginning of the eighteenth centuries, and whose periodicals furnished ever-accumulating data for the discussion of old and the initiation of new theories, and disseminated the results of chemical investigations in general, assisted materially toward the healthy progress of chemical science; but nevertheless firm obsequiousness to any one school of scientific thought was not to be expected, nor was it found.

The London Royal Society was founded by Charles II., and was incorporated by him in 1662, under a royal charter, for the improvement of natural knowledge. The first volume of the "Philosophical Transactions" of that society bears the date 1665, and ever since its foundation the Royal Society has been a nucleus around which has clustered the scientific genius of Great Britain. In 1666, the Academie Royale was instituted in Paris under the protection of Louis XIV., and its "Memoires" began to appear in 1699. Other scientific societies—the Accademia del Cimento of Florence (1657), the Academia Naturæ Curiosum of Vienna (1652), and the Berlin Academy (1700)—also brought together those who were in sympathy through their devotion to knowledge, and by the interchange of their ideas thought was quickened and the advance of science aided. The reciprocal action of chemistry and allied branches of science upon each

other was also promoted by bringing together their respective exponents, and the discussion of scientific researches helped more thoroly to sift the evidence on which their conclusions were based, and tended to promote increased accuracy and simplicity of thought and expression.

Altho the literature of the day bears record of many observations, isolated discoveries, and discussions on chemical problems, yet there was one problem which engrossed the attention of almost all philosophers during the seventeenth and eighteenth centuries, and this was the explanation of fire and the phenomena caused by fire. Notwithstanding the fact that here scarcely any two chemists were agreed in their conclusions, their modes of arriving at them showed remarkable similarity. Little note was taken of the proportions by weight in which substances entered into reaction, the qualitative side of phenomena alone being considered.

This period of about one hundred and twenty years, from Boyle to Lavoisier, may therefore be described as that of Qualitative Chemistry—a step toward the quantitative work of the Modern period, and an immense step forward from the speculative and fortuitous chemistry of the preceding periods. It was a period of generalization, for just as fire was to be explained by the assumption of one general principle, "phlogiston"—a doctrine which influenced chemists to such an extent that this period is characterized as the Phlogistic Period—so the general properties of acidity and causticity were to be viewed as conferred by one fundamental acid and one fundamental alkali respectively; and altho it was itself handicapped by erroneous views, the Phlogistic Period contributed largely to the refutation of alchemical and iatro-chemical errors, and was a highly productive period for chemistry.

Robert Boyle (1627-1691) was the seventh son and fourteenth child of Richard, Earl of Cork. He was born at Lismore, in Munster. At eight years of age he was sent to Eton, where, says he, a perusal of "Quintus Curtius" "conjured up in me that unsatisfied appetite for knowledge that is yet as greedy as when it was first raised." After about four years at Eton, Boyle went to his father's seat in Dorset and afterward traveled. He became a student at Geneva and continued his studies at the manor of Stalbridge from 1644 to 1654, when he settled at Oxford. In 1668 Boyle moved to London and was a prominent member of the then newly constituted Royal Society. He was elected president in 1680, but refused to serve, owing to a scruple he entertained as to taking oaths. In 1689 his health began to fail and he issued an advertisement restricting the visits of his acquaintances. He also had a board put up outside his house announcing when he received visits. Boyle's health had never been good; from the age of twenty-one he suffered from stone, and much feared that

if it forced him to take to his bed the pain of it would become intolerable. He died, however, without pain, and almost without serious illness.

Boyle developed talent early, and at twenty-one he had already written on ethics and published several moral and religious essays. In 1665 he published his "Occasional Reflection upon Several Subjects," which procured him the satire of Swift in "A Pious Meditation upon a Broomstick, in the style of the Honorable Mr. Boyle."

It would be needless to attempt to go over the whole ground of Boyle's work, altho there is much in it of interest even at the present time, as, for example, his papers on the "Saltness of the Sea," and the "Nature of the Sea's Bottom," and his "Essay of the Intestine Motions of the Particles of Quiescent Solids wherein the absolute Rest of Bodies is called in question." He was perhaps the first to draw attention to the desirability of studying the forms of crystals, and his paper on the "Figures of Salts" contains many curious observations; in his "Experiments about the Superficial Figures of Fluids, especially of Liquors contiguous to other Liquors," he breaks ground which has taxed the energies of our greatest mathematicians. His "Treatise on Cold" abounds with striking and original experiments; for example, he demonstrates the expansive power of freezing water by bursting a gun barrel filled with water and securely plugged, by placing it in a mixture of snow and salt, a freezing mixture which he himself introduced in England. His "Essays on the Usefulness of Experimental Natural Philosophy" were of the greatest service in his time in furthering the cause of science by showing how the material interests of civilization may be promoted by its study; and, lastly, his tract on "Unsucceeding Experiments" must have been, to quote Thorpe, "as the wine of gladness and the oil of consolation to many a despondent virtuoso."

Boyle was born in the year in which Bacon died; and Boyle's place in the history of science is that of the first true exponent of the Baconian method, and the "Sceptical Chymist" is his greatest work. This work probably contains a greater number of well-authenticated facts than is to be found in any other chemical treatise of its day.

But the real merit of this work consists in its determined attack on the authority of the Peripatetics and the Paracelsians. To quote from his own statement in "The Sceptical Chymist":

"To acquaint you with divers of the conjectures (for I must yet call them no more) I have had concerning the principles of things purely corporal: for though, because I seem not satisfied with the vulgar doctrines, either of the Peripatetick or Paracelsian schools, many of those, that know me, . . . have thought me wedded to the Epicurean Hypothesis (as others have mistaken me for a

Helmontian). . . . I should tell you, that I have sometimes thought it not unfit, that to the principles, which may be assigned to things, as the world is now constituted, we should, if we consider the great mass of matter, as it was whilst the universe was in making, add another, which may conveniently enough be called an Architectonick principle or power; by which I mean those various determinations, and that skilful guidance of the motions of the small parts of the universal matter by the most wise Author of things, which were necessary at the beginning to turn that confused chaos into this orderly and beautiful world. . . . For I confess I cannot well conceive, how from matter, barely put into motion, and then left to itself, there could emerge such curious fabricks, as the bodies of men and perfect animals, and such yet more admirably contrived parcels of matter, as the seeds of living creatures."

Boyle is severe upon the affected mysticism of the Spagyrists. They may be as obscure as they like about their elixir, and the rest of their grand arcana, "yet when they pretend to teach the general principles of natural philosophers, this equivocal way of writing is not to be endured. For in such speculative inquiries where the naked knowledge of the truth is the thing principally aimed at, what does he teach me worth thanks, that does not, if he can, make his notion intelligible to me, but by mystical terms and ambiguous phrases darkens what he should clear up, and makes me add the trouble of guessing at the sense of what he equivocally expresses, to that of learning the truth of what he seems to deliver."

Indeed, Boyle does not hesitate to say that the reason why the Spagyrists wrote so obscurely of their three great principles was, according to Thorpe, "that not having clear and distinct notions of them themselves, they could not write otherwise than confusedly of what they had confusedly apprehended: they could scarcely keep themselves from being confuted but by keeping themselves from being clearly understood—home thrusts which must have made many a Helmontian wince. The effect of such hard hitting is made evident on the most superficial comparison of the general style of chemical treatises immediately preceding Boyle's time with those published toward the close of the seventeenth century."

The "Sceptical Chymist" compelled the decline of the doctrine of the "tria prima," and before the close of the century the Paracelsians were as much out of date as a Phlogistian would be to-day. Boyle indeed appeared to incline to the belief that all matter is compounded of one primordial substance—in other words, that all matters are merely modifications of the "materia prima."

To quote again from his "Sceptical Chymist":

"I consider, that if it be as true, as it is probable, that compounded bodies differ from one another but in the various textures resulting

from the bigness, shape, motion, and contrivance of their small parts, it will not be irrational to conceive, that one and the same parcel of the universal matter may, by various alterations and contextures, be brought to deserve the name, sometimes of a sulphureous, and sometimes of a terrene, or aqueous body."

How closely he was in accord with the modern spirit is shown in this remarkable passage: "I am apt to think that men will never be able to explain the phenomena of nature, while they endeavor to deduce them only from the presence and proportions of such or such material ingredients, and consider such ingredients or elements as bodies in a state of rest; whereas indeed the greatest part of the affections of matter, and consequently of the phenomena of nature, seem to depend upon the motion and contrivance of the small parts of bodies."

It was possible for Boyle to expose the shortcomings and fallacies of the then prevalent idea of Element or Principle: "I mean by elements, as those chymists, that speak plainest, do by their principles, certain primitive and simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved. I need not be so absurd, as to deny, that there are such bodies as earth and water, and quicksilver and sulphur: but I look upon earth and water, as component parts of the universe, or rather of the terrestrial globe, not of all mixt bodies."

This conception of an element gave the term a positive meaning.

Boyle also looked forward to the discovery of a much greater number of elements than was at that time assumed, at the same time maintaining that many of the substances then held to be elementary were not really so. Boyle was the first to state clearly that a chemical compound results from the combination of two constituents, and that it has properties entirely different from those of either of its constituents alone. He was, therefore, enabled to draw a sharp distinction between mixtures and chemical compounds, and to grasp clearly the main problem of chemistry—the investigation of the composition of substances. In doing this he had the solid ground of experience and experiment under his feet, and could always bring forward evidence for the probability of his views. His endeavors to get at the root of the composition of bodies gave an impetus to analytical chemistry, which before his time could hardly be said to exist; and we are at the same time indebted to him for fixing the meaning of a "chemical reaction." Boyle appears to have been the first to employ the term analysis, in the sense in which it has since been used by chemists.

Also he devoted much attention to the inquiry of the cause of

combustion and other similar phenomena, and altho his attempts at explaining these were not very successful, his experiments on the rôle played by air in combustion aided the later solution of the problem. His investigations on air and gases led him in 1660 to the well-known discovery of the law that "the volume of a gas varies with the pressure" (Marriotte educed this independently in 1677).

Boyle's writings, which were extensively read in his own time, are characterized by simplicity of style and clearness of expression; they offer, as von Meyer observes, "an agreeable contrast to the works of many of the other chemists of his time, who sought to hide their deficiencies in clear thought and accurate knowledge by metaphorical and mysterious language." In addition to other papers published in the "Philosophical Transactions," the following works of his, which were brought out both in English and Latin, are to be particularly mentioned: "The Sceptical Chymist" ("Chemista Scepticus"), first published anonymously in 1661, and afterward in many editions with Boyle's name as author; "Tentamina quæ dam Physiologica" (1661); and "Experimenta et Considerationes de Coloribus" (1663). Editions of his complete works were published in London in 1700, 1725, and 1744.

A contemporary of Boyle who made important observations on combustion was Robert Hooke (1635-1702).

Hooke was born in the Isle of Wight and was originally intended for the Church, but he was of a weakly constitution, and much subject to headache, and owing to these causes the idea was finally abandoned. His learnings were first shown in a considerable aptitude, as a boy, for constructing mechanical toys. After his father's death Dr. Busby took him into his house and supported him while at Westminster School. After leaving school he went to Christ Church, Oxford, and, in 1655, he was introduced to the Philosophical Society. Here his talents were speedily discovered and he was employed to assist first Dr. Willis and then Mr. Boyle. In 1662 he was made curator of experiments to the Royal Society, and when this body was established by charter he was one of the first nominated to fellowship. He obtained several professional posts and in 1665 he published in folio his "Micrographia, or some physiological descriptions of minute bodies made by magnifying glasses, with observations and inquiries thereupon." It was dedicated to Charles II.

It is usual to state that Hooke anticipated the modern view of the nature of combustion in this treatise; but it will appear from the following extract that whatever value may be assigned to his work, it cannot be claimed that he did more than recognize the part played by the air in the process, while still adhering to the conception of "sulphureous principle" which is lost by the body during combustion. Thus he observes:

"From the experiment of charring of coals . . . we may learn . . . that the air in which we live, move, and breathe, and which encompasses very many, and cherishes most bodies it encompasses, that this air is the menstruum, or universal dissolvent of all sulphureous bodies . . . that the dissolution of sulphureous bodies is made by a substance inherent, and mixt with the air, that is like, if not the very same, with that which is fixt in saltpeter, which by multitudes of experiments that may be made with saltpeter, will, I think, most evidently be demonstrated. . . . The dissolving parts of the air are but few, that is, it seems of the nature of those saline menstruums, or spirits, that have very much flegme mixt with the spirits, and therefore a small parcel of it is quickly glutted, and will dissolve no more; . . . whereas saltpeter is a menstruum, when melted and red-hot, that abounds more with those dissolvent particles, and therefore as a small quantity of it will dissolve a great sulphureous body, so will the dissolution be very quick and violent. . . . It is observable, that, as in other solutions, if a copious and quick supply of fresh menstruum, though but weak, be poured on, or applied to the dissolublе body, it quickly consumes it: so this menstruum of air, if by bellows, or any other contrivance, it be copiously apply'd to the shining body, is found to dissolve it as soon, and as violently as the more strong menstruum of melted nitre."

The completion of Hooke's theory was effected by John Mayow, who was born in the parish of St. Dunstan, London, in 1645. In 1674 he produced the treatise on which his fame rests; it is entitled "Tractatus quinque medico-physici quorum primus agit de salnitro et spiritu itro-aëreo, secundus, de respiratione, tertius de respiratione fœtus in utero et ovo, quartus de motu musculari et spiritibus animalibus, ultimus de rhachitide; studio Joh. Mayow, LL.D. & Medici, nec non Coll. Omn. Anim. in Univ. Oxon. Socii. Oxonii e Theatro Sheldoniano, An. Dom. MDCLXXIV."

Mayow's assumption—that atmospheric air contains a substance, the "spiritus nitro-aërus" (also present in saltpeter), which combined with metals when they were calcined, and which sustained respiration and converted venous blood into arterial—was bound to result in the right interpretation of the phenomena of combustion, when the observations which had led to it were sufficiently extended. Mayow's early death in 1679 was perhaps the reason why this did not occur, the development of the new chemistry being greatly retarded as a result.

Two members of the French Academy became prominent at this period, Lemery and Homberg. Wilhelm Homberg (1652-1715) was a lawyer, but gave up the practice of his profession to study natural science and medicine. He knew both Boyle and Kunckel, and was a good observer and skilful in carrying out his experiments, but

a poor interpreter of results. He was trammeled by alchemistic views, maintained that substances consisted of mercury, sulphur, and salt, and took little part in establishing the new theories. He contributed a large number of papers on chemical, zoological, botanical, and physical subjects to the French Academy.

Nicolas Lemery (1645-1715) was especially renowned as a teacher, tho he was also a good worker, dealing in the practical rather than the theoretical. His son, Ludwig Lemery, was also a distinguished chemist. The elder Lemery's greatest work was the writing of his textbook of chemistry, "Cours de Chimie" (1675), which embraced all that was known of chemistry, and endeavored to give a suitable connection between the facts recorded, and to systematize them. This was for many years the best text-book on the science, and was issued in thirty-two editions. Thirteen editions appeared during the author's lifetime, and a last much-changed one was issued by Baron in 1756.

Two German contemporaries of Boyle were Johann Kunckel and Johann Joachim Becher. Kunckel was essentially an experimentalist; he was imbued with a belief in the Philosopher's Stone, and regarded mercury as the necessary component of a metal. He was born at Rendsburg in 1630, and died in 1702. He was the son of an alchemist, and himself passed much of his life as the employee of sundry German princes (among them the Elector John George of Saxony, the great Elector of Brandenburg, and the Dukes of Lauenburg) in the unsuccessful pursuit of the Philosopher's Stone.

Before the second half of the seventeenth century the blowpipe had been used neither in chemical analysis nor for working glass. It was Kunckel's task to demonstrate the ease with which a metallic calx might be reduced by heating it on charcoal before the blowpipe, and to institute a more expeditious mode of hermetic sealing than that of inserting the drawn-out neck of flask or other vessel in a hot fire, hitherto in vogue.

Kunckel was the first to recognize an analogy between putrefaction and fermentation, and to show how the production of vinegar in the latter process depended on the initial formation of alcohol and avoidance of low temperature or presence of acids. Among his treatises the following may be mentioned: "Oeffentliche Zuschrifft von dem Phosphoro mirabili und dessen deuchtenden Wunder-Pilulen" (1678); "Ars Vitraria Experimentalis" (1689); and Philosophia chemica experimentis confirmata" (1694).

CHAPTER VII

FIRE AS THE CREATOR

ONE of the most interesting chapters in the history of chemical science is that dealing with the study of the phenomena of combustion and their interpretations. As Freund observes, it lends itself specially well to the purpose of indicating within the scope of not too complicated phenomena, "how a theory arises, how it is applied, how the conversation inherent in the human mind is reluctant to give up an accustomed interpretation of nature, even when it no longer answers to the first requirements of a theory; that is, when it no longer explains the facts and laws observed in the class of phenomena to which it refers; but how after all facts are and always must be strongest, and hence how a theory is finally given up when no longer able to deal with the facts, and how its place is then taken by another better fitted to do so."

The effect of heat on matter had from early times been a subject for observation and experiment, which soon led to classification and generalization. It was observed that while some substances are not permanently changed when heated (sand, noble metals, etc.), others are (wood, sulphur, base metals, etc.). The burning of substances—that is the occurrence of a permanent change marked by the appearance of flame—greater evolution of light and heat, and the remaining behind of ash—naturally arrested attention and the view that substances were combustible in virtue of the common presence in them of "fire matter" goes back to the time of the Greek philosophers. That the substances left behind when wood is burnt or when metal such as copper and lead are heated, were alike called "cineres" (ashes), bears witness to the fact that even then these two phenomena, outwardly not very similar, the burning of wood and the change produced by heating metals, were already classed together.

The name of "calces" (Latin calx=lime) for burnt metals, which up to about 1600 was used along with "cineres," and after that exclusively, is due to the Arabian alchemists, and suggests an analogy with the burning of chalk, the burnt metal being produced from the metal by the same process as quick-lime from chalk, namely, by heating. All through the Middle Ages the idea was retained that what occurs when substances burn with flame, and when metals are changed

to calces, is of essentially the same nature and must therefore be explained by the same cause. For many centuries sulphur was looked upon as the principle of combustibility and metals which could be burnt"—*i.e.*, calcined—owed this to the common presence in them of sulphur. Thus, "Ubi ignis et calor, ibi sulphur," summed up this view. Becher's "terra pinguis" had much in common with the fire of the schoolmen and the sulphur of Albertus Magnus and Paracelsus. The scope of the phenomena to which this explanation of combustion applied was extended by Stahl, and the theory of the phenomena of combustion and other analogous processes which were to be explained by the assumption of the hypothetical phlogiston was the point round which chemists in general gravitated during the eighteenth century; until the appearance of Lavoisier the phlogiston theory received the assent of most investigators.

Georg Ernst Stahl, born at Anspach in 1660, devoted himself to the study of medicine and acquired, first at Jena and later on at Halle —to which university he had been called as professor of medicine and chemistry in 1693—the reputation of a distinguished physician and academic teacher. When he was appointed physician to the king in 1716, he removed to Berlin, where he successfully strove for the extension of chemical knowledge until his death in 1734. He investigated chemical problems in the true scientific spirit; himself guided by the ardent desire to discover the truth, he was able to draw around him pupils animated by a similar purpose. The most eminent among the Berlin chemists of the succeeding generation studied under him.

Even in his own lifetime the doctrines which he taught, together with a number of valuable detached observations, were widely disseminated by means of his writings and especially by his lectures, the later of which were published by several of his pupils. Stahl, however, exercised his greatest influence both upon his contemporaries and upon the succeeding generation by his phlogiston theory, which eclipsed all his other chemical work.

Phlogiston was defined by Stahl as "materia aut principium ignis, non ipse ignis," and was conceived to be "a very subtle matter, capable of penetrating the most dense substances; it neither burns, nor glows, nor is visible; it is agitated by an igneous motion ('igneo motu'), and it is capable of communicating its motion to material particles apt to receive it. The particles when endued with this rapid motion constitute visible fire. . . . The igneous motion is 'gyratorius seu vorticillaris.' . . . Heat is an intestine motion of the particles of matter."

Phlogiston was a new name for an old principle. We know that the idea of the existence of a subtle fire innate in matter has pervaded physical philosophy from the earliest times. Phlogiston was, as Rodwell notes, another name for the "pure fire" of Zoroaster; the ατεκνε-

κον πυρ of Zeno; the "subtilis ignis" of Lucretius; the "elemental fire," "astral fire," "sulphur," or "sulphureous principle" of the chemists; the "calor cælestis" of Cardanus; the "sideric sulphur" of Paracelsus; the "materia cælestis" of Descartes, and the "terra inflammabilis" of Becher. The functions of this entity had been varied by different thinkers, almost as much as its name, until Descartes gave them accurate definition. The theory of phlogiston was the theory of the "Materia Cælestis" extended in a chemical direction. Phlogistic chemistry was Cartesian chemistry. Descartes defined the physical functions of the "Materia Cælestis," while Becher and Stahl defined its chemical functions and applied them to the explanation of diverse chemical phenomena. Throughout the writings of Becher and Stahl we find a sprinkling of Cartesianism; they did not, however, adopt the system in its entirety, but appear to have discarded the second and third elements, and adopted the first as the parent of their own system.

The theory of phlogiston was essentially and completely a syncretistic theory. It was built up, as Rodwell observes, of "idola theatri," collected from various sources, and these were cemented together by the particular "idola specus" of Becher and Stahl. In this process of syncretism the merit of these men lay; their fault was a too hasty generalization. In that stage of chemistry syncretism was inevitable; indeed, all theories are more or less tinctured by it, with the exception of those which emanate from a new mode of experimenting, such, for example, as Kirchhoff's theory of the constitution of the sun. A theory proceeds by slow evolution until it dominates or is destroyed, and it was thus with the theory of phlogiston.

Arising under the most favorable conditions, it attained full development, became most cardinal, most sovereign, and then fell. For twenty-eight years it was looking a half-formed thing through the mists of chemistry; for thirty-four years it was growing in strength and proclaiming its dynasty; for fifty-four years it was dominant, and it was fully ten years yielding up the ghost. Becher and Stahl were the prophets of a new mode of chemical thought, essentially classificatory, systematic, and syncretistic. In their day chemistry was at the commencement of a period of transition, and they bridged the gap which existed between empirical chemistry and modern chemistry. They did not collect the materials for the structure—they did not altogether construct it, but they designed it, and helped in the work of building. Altho a bad bridge, and built upon shifting sands, yet it was a channel of escape from mystic science, and many passed over to take refuge on the other side.

To Stahl, however, belongs the merit of grouping together the phenomena of oxidation and reduction, as we now term these, albeit by the aid of a false hypothesis. The addition of phlogiston is equivalent to reduction and its withdrawal or escape to oxidation. The analogy be-

tween respiration and the decomposition of animal matters on the one hand and combustion on the other did not escape Stahl, who likewise assigned the chief rôle in these processes to phlogiston.

The value of his theory lay therefore in the interpretation which it afforded of a variety of processes from one common point of view. The simplicity of this explanation blinded both himself and the generation which followed him to such a degree that they left unnoticed all the glaring contradictions between many actual facts and the phlogistic doctrine. Notwithstanding this, however, the latter was not an obstacle to the development of chemistry, considering that chemists like Black, Cavendish, Marggraf, Scheele, Bergman, and Priestley, who so greatly extended the science by their wide-reaching discoveries, were phlogistonists in the full sense of the word.

Stahl's two most famous contemporaries were Friedrich Hoffmann and Hermann Boerhaave. Hoffmann, born at Halle in 1660, after acquiring a thoro knowledge of medicine, mathematics and the natural sciences, practised first as a physician and then became professor of the science of medicine in Halle, where he ultimately died in 1742, after an interregnum spent in Berlin. His most important work was done in medicine, and in pharmaceutical and analytical chemistry. He combated with success the iatro-chemical doctrines of Sylvius and Tachenius, which still held their ground with many physicians, exposing their absurdities and showing to what nonsensical deductions such exaggerations led.

Hoffmann's views on combustion were very similar to those of Stahl. With respect to the calcination of the metals and the reduction of their oxides, however, he expressed opinions which approximate to those held at the present day, believing, as he did, that metallic "calces" contained a "sal acidum" in addition to a metal, the former of which escaped when the "calces" were reduced. This assumption did away with the similarity between combustion and calcination; these phenomena became indeed rather opposed to one another thereby, and with this the special use of the phlogiston theory vanished. Hoffmann was a very voluminous author, and his collected works in six volumes and five supplements, entitled "Opera Omnia Physico-medica" (1740-1760), show clearness of style and precision of expression. Gmelin in his "Geschichte der Chemie" enumerates 122 chemical treatises of Hoffmann.

Hermann Boerhaave was born at Voorhout, near Leyden, in 1668, where he received his education and became professor of medicine and afterward of chemistry and botany. The thirty-six years of his residence there were the most brilliant in the history of this university. Looking at his chemical work alone, he is found distinguished in the main as a teacher and for his skill in interpreting chemical facts and

the clearness of his theoretical views. He exposed the errors of the iatro-chemists and recognized chemistry as a distinct science.

He also showed the falsity of the views held by the alchemists. He spoke only of things tested and observed by himself, and spared neither pains nor time to have his observations correct. For instance, the alchemists maintained that mercury could be fixed in the form of a fire-proof metal, without the addition of any other substance. Boerhaave kept mercury at a somewhat raised temperature in an open vessel for fifteen years without noting any change. So, too, when heated higher in a closed vessel for six months no change could be discovered. This convinced him that the fixing of mercury was an impossibility. The alchemists said also that if mercury was repeatedly distilled, a more volatile essence with peculiar properties could be obtained. Boerhaave carried out this distillation five hundred times without securing the essence. And so he tested other of their peculiar notions and prescribed methods without obtaining the results promised; and as the methods were still credited in some quarters, he did good service in disproving them, and won for himself the reputation of being a most excellent and painstaking worker.

His lectures were published first in the "surreptitious edition," "Institutiones et Experimenta Chemiæ" (1724) and afterward corrected by him under the title "Elementa Chemiæ" (1732). Eleven editions and translations were published in Germany, France, and England.

Boerhaave appears to have concurred in the phlogiston theory in many points. At least he expressed no opinions contrary to Stahl's fundamental views, altho he did not agree in regarding the "calces" of the metals as the earthy elements of these latter.

The influence of Stahl's doctrine manifested itself more immediately in Germany, where it received the almost unequivocal support of chemists, Berlin remaining the center point of this theory. Among the men who upheld and endeavored to propagate it, Marggraf was the most active.

Kaspar Neumann (born 1683) and Johann Theodor Eller (born 1689), contemporaries of Stahl, were also active adherents of the doctrine in Berlin. Both of them, as professors at the Medico-Chirurgical Institute, were in a high degree active in maintaining and disseminating a knowledge of chemistry. Their own observations were, however, of little importance; Neumann made the first accurate observation of the acid obtained from ants; and the views of Eller were chiefly upon subjects of medical physiology, and are full of crude speculations. Stahl's pupil, Johann Heinrich Pott (born 1692), improved chemistry by many valuable observations, but he was unfortunate in his explanation of these. He regarded boracic acid, for instance—a substance which he had himself investigated carefully—as consisting of copper vitriol and borax. The results which he achieved were not, as von

Meyer notes, at all commensurate with his untiring perseverance, which he showed, among other ways, in his endeavors to prepare porcelain. Altho an adherent of the phlogistic doctrine, Pott did not bring forward anything new in its favor; with regard to the nature of phlogiston itself, he could only express the opinion that it was "a variety of sulphur." A notable achievement associated with his name was a wide extension of the method of dry analysis. His "Chymische Untersuchungen" was published in Berlin in three parts in 1757.

Neumann's pupil, Marggraf, was the last of the well-known German chemists of the phlogiston period. Andreas Sigismund Marggraf was born at Berlin, in 1709, and proved a most able experimenter; indeed, it is for his many isolated discoveries that he is remembered rather than for any influence exerted on the general trend of chemical philosophy. One of the most lasting benefits owed to him is the introduction of the microscope as an aid in laboratory work. The occasion was noteworthy. A paper appeared in the memoirs of the Berlin Academy for 1745, in which Marggraf stated that small crystals of sugar might be seen with the aid of a microscope upon the finely divided and desiccated roots of the carrot and beetroot. He further stated that this sugar could be extracted by lixiviation with hot alcohol, and added that mere compression of carrot or beet would yield a saccharine liquid, from which the sugar might readily be extracted. These observations remained unnoticed, until the continental blockade of France in 1806 urged its people to find some substitute for their imported sugar.

Of prime importance were Marggraf's observations on phosphoric acid, whose principal physical and chemical properties he accurately described. He obtained this acid by burning ordinary phosphorus in the air, and dissolving the resulting "fleurs de phosphore" in water; also by heating phosphorus with concentrated nitric acid. Marggraf's work on the composition of gypsum was remarkable; he had noticed that potassium sulphate on heating with charcoal emitted the pungent smell of burning sulphur, and as this also occurred when gypsum or heavy spar was substituted for the potassium salt, they too must be compounds of sulphuric acid. One should not forget his introduction of potassium ferrocyanide as a reagent for iron, nor his separation of microcosmic salt from urine; he remarked that it was this salt which contained the phosphorus.

With great talent for observation Marggraf united the gift of deducing what were generally sound conclusions from his work. In one point, however, Marggraf, like all phlogistonists, was not in a position to do this; altho he had himself proved that phosphorus increases in weight by conversion into phosphoric acid, he could not free himself from the idea that phlogiston escaped during this process of combustion. And he could never be brought to see that this conception was an

erroneous one, altho the anti-phlogistic doctrine was brought out several years before his death. Marggraf's papers are, as mentioned, almost all contained in the "Memoirs" of the Berlin Academy; most of them were published from 1761-1767 in two volumes, under the title "Chymische Schriften." A French edition appeared in 1762.

In France, the principal exponents of chemistry during the eighteenth century, until the downfall of the phlogistic system, were Geoffroy, Duhamel du Monceau, Rouelle and Peter Joseph Macquer.

Stephen François Geoffroy (the elder, to distinguish him from his less celebrated young brother, Claude Joseph, whose work was chiefly pharmaceutico-chemical) was born in Paris in 1672, and helped for some time in his father's apothecary shop; he gave himself up, however, to chemical and medical studies, and labored with great success as professor of medicine in the Jardin des Plantes from the year 1712 until his death in 1731. Geoffroy became well known throughout the scientific world by his researches upon chemical affinity; his "Tables des Rapports" (tables of affinity), in which the results of his most important observations are collected, exercised a great influence upon the doctrine of affinity. His theoretical views were less idoneous—*e.g.*, he looked upon the iron found in the ashes of plants as having been produced artificially during the process of ignition.

Geoffroy's views on combustion were in principle those of Stahl, though he expressed himself in the nomenclature of the earlier period; yet there was much promise in his conviction that the different "calces" were radically different bodies.

A real service was rendered by him by the energy with which he attacked alchemistic frauds, subjecting these as he did to critical examination in the memoir "Des Supercheries concernant la Pierre Philosophale," presented to the French Academy. Geoffroy's treatises were published partly in the "Memoirs of the French Academy," and partly in the "Philosophical Transactions." His long-celebrated work, "Tractatus de Materia Medica," shows that he regarded chemistry as a sister science and an invaluable aid to medicine.

Henri Louis Duhamel du Monceau (born 1700, died 1781), of the school of Lemery and Geoffroy, spent his life in Paris, where his versatility gained for him a high reputation. His sterling work was not by any means in pure chemistry alone, but also in physics, meteorology, physiology, botany, and particularly in chemistry as applied to agriculture.

Duhamel's great achievement was the differentiation of the two alkalis, soda and potash. The composition of ordinary salt had hitherto eluded research. Stahl, it is true, believed one constituent to be an alkali, and an alkali quite different from potash, if one might judge by differences in the crystalline form and solubilities of their respective salts. There was a vagueness about his work, however, and

it had met with little recognition. Duhamel published a paper in 1736 on sea salt which put the matter beyond question. In it he first showed that the base of salt was not an earth, for the addition of potash caused no precipitation, then that its several salts all differed essentially from those of potash corresponding. He laid stress too, on the fact that the further one moves from the sea, the less quantity of the new base and the greater the quantity of potash in the surrounding vegetation. Subsequently, while describing minutely the differences between the analogous salts of these bases, Duhamel mentioned the yellow and violet colorations which they respectively give to a colorless flame.

While Duhamel worked mainly as an academician, Guillaume François Rouelle (born 1703, died 1770) was occupied in teaching at the Jardin des Plantes, and some of his pupils, particularly Lavoisier and Proust, attained the highest eminence. At the same time he was also busy as an investigator, as many admirable observations and conclusions drawn from the latter show. Rouelle fixed the meaning of the term "salt" (in the "Memoirs" of the Academy for 1745) from a far more general point of view than van Helmont or Tachenius had done. The composition of a substance alone was sufficient to tell him whether it belonged to the class of salts or not. Salts were produced by the combination of acids of every kind with the most various bases; and in addition to neutral salts, he drew a distinction between acid and basic ones. With views so lucid as these, Rouelle was far ahead of his contemporaries.

Rouelle's "Cours de Chimie," according to Hoefer, exists only in manuscript.

The last of the French chemists of renown to adhere to the phlogistic theory was Pierre Joseph Macquer, who was born at Paris in 1718. He became a member of the French Academy at the age of twenty-seven. Excellent opportunity for work was afforded him by his position as professor at the Jardin des Plantes, and his methods of research were more like those of the present. He determined the solubility of various salts in alcohol, and used this as a means of separating them from one another. Some of his researches were on potassium arseniate, and on the coloring matter of Berlin blue. The latter he identified with phlogiston because it was destroyed on heating. He was the author of several text-books, "Elemens de Chymie Theorique" (1749) and "Elemens de Chymie Pratique" (1751), which were highly thought of; but his chief work was his "Dictionnaire de Chymie," which appeared first in 1766. This was the first dictionary of chemistry, and it was enlarged three times, and translated into English, German, Italian and Danish. Macquer died in 1784. All his life he remained a phlogistonist, and did all that he could to reconcile the continually augmenting dissidences between theory and facts; he paid no attention to proportions by weight, for it was only in this way that

he could maintain the phlogistic hypothesis. And even although it was proved to be erroneous and untenable several years before his death, he was still unable to relinquish it.

During the eighteenth century many distinguished chemists flourished in Great Britain and Sweden, all of whom were adherents to the phlogiston theory of Stahl, and this notwithstanding the fact that it was their investigations, particularly those of Black, Cavendish, Priestley, Scheele, and Bergman, which destroyed the foundations of this theory.

Black was born near Bordeaux in 1728, and died in Edinburgh in 1799. His father, a wine-merchant, was originally a native of Belfast, being descended from a Scotch family which had been settled there for some time. Black's original thesis for his degree was entitled "Experiments upon Magnesia Alba, Quicklime, and other Alcaline Substances." It was published in 1755, and was reprinted in 1777 and 1782. During the ten years he was Professor of Medicine at the University of Glasgow he began and made great progress with his well-known researches on the heat of fusion of ice, and the heat of vaporization of water, or, as he termed them, the "latent heats" of water and of steam.

The carbonates of the alkaline earths were before Black's time regarded as simple substances; and it was also supposed that when limestone was burnt fire-stuff was taken up, and that this went over into potashes or soda when these were causticized by means of lime. Black, on the other hand, showed by his investigations that when limestone (carbonate of lime) or "Magnesia alba" was calcined, something escaped which caused a loss of weight and which was identical with van Helmont's "gas sylvestre." This gas—which he termed "fixed air" on account of its being held bound by caustic alkalies, lime, etc.—he proved to be also present in the mild alkalies; and these latter became caustic when deprived of their carbonic acid by lime or magnesia. In this research methods are met with which have the imprint of a new departure. That Black devoted great attention to the proportions by weight of the compounds which entered into the reaction is seen in all his investigations; and it is thus easy to understand how he gave up the phlogiston theory and concurred in the doctrine of Lavoisier when the correct explanation of combustion and similar processes became possible through the discovery of oxygen.

Cavendish, the distinguished co-worker and fellow countryman of Black, was born at Nice in 1731, two years before Priestley; but, notwithstanding his brilliant circumstances, he lived the life of a recluse, devoting himself entirely to the furtherance of his beloved science. He died in 1810. His most important work was the discovery of hydrogen, which he called "inflammable air." This he distinguished

from the "fixed air" of Black, concluding that this "inflammable air" was the unalterable phlogiston of metals. He was the first to attempt to determine the specific gravity of the gases. He showed that lime carbonate was held in solution in water by dissolved fixed air or carbonic acid. He proved in his experiments on air that when hydrogen was burned water was formed, thus really determining the composition of water, tho he did not recognize this fact. This led to a sharp controversy as to the phlogistication of the air or atmosphere, and in the hands of that great interpreter of results, Lavoisier, did much to clear up and advance chemical theory.

The opposition of Cavendish to the antiphlogistic doctrine, which he helped to found by his own investigations, can only be explained by the fact that he did not take the proportions by weight in the processes of combustion into due consideration, but interpreted the latter in a manner which appeared to him sufficiently convincing, viz., by regarding hydrogen, "inflammable air," as identical with phlogiston.

In addition to this Cavendish showed a wonderful exactitude in his researches upon gases, whose specific gravities and volume-ratios in chemical reactions he established. With what ingenuity he thought out and carried through physical experiments is well illustrated in his work on the specific heats of metals, and in his attempt—the first one which was successful—to determine the specific gravity of the earth. Another instance will be fresh in the memory of most readers, viz., Cavendish's suspicion, from the results of his own experiments on the combination of oxygen and nitrogen, that there was possibly still another gas present in the air in small quantity (argon). When this marvelous versatility is considered and the thoro mathematical training that Cavendish had gone through is remembered, the wonder seems great that he laid too little stress upon proportions by weight in chemical reactions.

Joseph Priestley was born at Fieldheads, near Leeds, in 1733, and received his education at a public school and at an academy of the Dissenters. His studies were theological in character, and he became a dissenting minister. He was not a success in this work, becoming extremely unpopular even with his own sect. He also conducted a school, but was in very needy circumstances. He was able, however, to buy a few books and some instruments, including a small air-pump, an electrical machine, etc., and was tireless in his work, training himself and his scholars in natural science. Meeting Franklin in London, he was attracted to the study of electricity, and wrote a history of electricity. This, together, with some new experiments on electricity performed by him, won some outside reputation and his election as Fellow of the Royal Society.

He moved to Leeds, settling near a brewery. This gave him opportunity for examining the "fixed air" discovered by Black, and which

had been shown to be one of the products of fermentation. He collected this gas from the vats, and performed many experiments with it. Moving away from the brewery, he had to prepare the "fixed air" for himself; and this led to his devising the simple and useful pneumatic trough. In the heated times of the French Revolution, his church and dwelling-house were mobbed and burned, his library and apparatus destroyed, and he himself escaped with difficulty to London, and finally took refuge in America, where he settled in Pennsylvania. In this country he pursued his scientific experiments, discovering carbon monoxide. He died in retirement in the year 1804. One French historian, Henri Gautier, states in his "Essai sur l'histoire de la Chimie" that Priestley "sought an asylum among the Indians, and eventually he and his entire family died by poison!"

Priestley was a brilliant investigator, performing many most striking experiments. He was, however, neither thoro nor very careful, and was lacking in the scientific acumen needed for the proper interpretation of his results. It was upon the gases that his most valuable work was done; his invention of the pneumatic trough enabling him not only to discover new gases, but to investigate the properties of many already partially known. He considered that "More is owing to what we call chance . . . than to any proper design or preconceived theory in this business," and shows how large a share this element of chance had in his discovery of the new gas, oxygen.

His method of experimenting is well illustrated by his own account of his discovery of oxygen (1774): "Having procured a (burning) lens, I proceeded with great alacrity to examine, by the help of it, what kind of air a great variety of substances would yield, putting them into vessels filled with quicksilver, and kept inverted in a basin of the same. After a variety of other experiments, I endeavored to extract air from 'mercurius calcinatus per se,' and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express, was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss how to account for it." His experiments showed him that this air "had all the properties of common air, only in much greater perfection"; and he called it "dephlogisticated air," regarding it simply as very pure ordinary air. In 1843, Cuvier endeavored to show that the French chemist Bayen preceded Priestley in the discovery of oxygen. Bayen, however, in reducing "precipitate per se," noted only the metal and entirely disregarded the escaping gas.

He seems to have looked upon all gases as easily changeable, one into the other, at least in the first period of his work. Many experiments were made by him on the action of the various gases known to

him upon animals and plants. He would place a mouse in a jar of the gas, and notice the effect upon its breathing and general life processes. Plants were grown in similar jars, and the result upon the growth noted. He showed that air which had become noxious through breathing or the burning of a candle could be restored to its original condition by growing a plant in it. This, he said, was due to the impregnation with phlogiston in the first case, and its removal in the second. "It is very probable," he wrote, "that the injury which is continually done to the atmosphere by the respiration of such a number of animals as breathe it, and the putrefaction of such vast masses, both of vegetable and animal substances exposed to it, is, in part at least, repaired by the vegetable creation." He was unable to explain how this was accomplished.

He held that all combustible bodies contained hydrogen. This was, in his view, phlogiston. The metals contained it, and their "calces," or oxides, were simply the metals deprived of hydrogen. Thus, he showed that when iron oxide was heated in hydrogen gas the hydrogen was absorbed and metallic iron formed. Rich iron slag or cinder was, in his opinion, iron with some hydrogen retained. To prove this, it was mixed with the carbonates of the alkaline earths and heated strongly. This gave him an inflammable gas, and all inflammable gases were hydrogen in a more or less impure condition, according to his belief.

That water could be impregnated with carbon dioxide was found out by him, and its use in disease suggested. Nitrogen dioxide and carbon monoxide were discovered by him, but his greatest discovery was that of oxygen gas. He examined sulphur dioxide, hydrochloric acid, and ammonia in the gaseous form. These are only the most important of his discoveries. Inaccurate in his experiments, he was decidedly weak as a theorizer. He was a firm believer in the phlogiston theory, and endeavored to explain the various phenomena noted by him by means of it.

The important works of Priestley are the following: "Directions for impregnating Water with Fixed Air in order to communicate to it the peculiar spirit and virtues of Pyrmont Water, and other mineral waters of a similar nature" (1772); "Philosophical Empiricism" (1775); "Experiments and Observations on Different Kinds of Air" (1774-1779); "Experiments and Observations relating to various branches of Natural Philosophy with a continuation of the Observations on Air" (1779-1786); and "Experiments on the Generation of Air from Water" (1793).

Bergman's system of wet analysis first took form during an investigation of natural waters; but he later made it embrace the examination of minerals in general, fusing such of these as were insoluble in hydrochloric acid with carbonate of potash. Bergman laid great

stress on the analytical value of the blowpipe, between whose inner and outer flame he discriminated; and he endeavored to extend the use of such reagents as soda, borax, and microcosmic salt, substances whose value had been demonstrated by the mineralogist Cronstedt. It is to Bergman's pupil Gahn that the introduction of cobalt solution as a reagent is owed, and the substitution of platinum wire for the gold or silver used hitherto. Up to this time, reduction to the metallic state had been regarded as a necessary precedent to the quantitative estimation of metals in combination. Bergman now introduced the revolutionary method of combining them in stable salts of known composition, and from the weight of these calculating the metallic content.

Bergman's analyses were not very accurate, yet they enjoyed the widest popularity; on the other hand, his German contemporary, Carl Friedrich Wenzel, found little consideration, tho his method was similar, and his results more fortunate. Meanwhile, the number of chemists who applied themselves to the quantitative side of phenomena was steadily increasing, an indication of the straits to which the phlogiston theory had been reduced. Yet at this eleventh hour Bergman set to work to determine the relative quantities of phlogiston in metals. Believing that metals only dissolve after conversion into their "calces," he ascertained those weights of various metals which precipitated the same weight of some other in solution, surrendering their phlogiston to its "calx"; these weights, to his mind, contained the same quantity of phlogiston.

He knew well how to render his chemical experiences useful for the definition and classification of minerals, and thereby laid the foundation of mineralogical chemistry and chemical geology. The current views upon chemical affinity gained through him precision and clearness; the scientific character of chemistry was materially raised by such observations, and a general survey of chemical processes rendered much easier. His papers appeared originally in the "Memoirs" of the Academies of Stockholm and Upsala; later on they were collected together and published in six volumes in 1779-1790, under the title "Opuscula Physica et Chemica." This Latin edition was translated into English in 1784-1791.

Carl Wilhelm Scheele was born in 1742 in Stralsund, the capital of Swedish Pomerania, where his father was a merchant and a burgess. He was the seventh of eleven children. After receiving his education, partly in a private school, partly in the public school ("gymnasium") at Stralsund, he was apprenticed at the age of fourteen to the apothecary Bauch in Gothenburg. In those days an apothecary was in large measure a manufacturer as well as a retailer of drugs. He had to prepare his medicines in a pure state from very impure materials, as well as to mix them in order to carry out prescriptions; and, indeed, he himself often, as sometimes happens still, ventured to prescribe in

mild cases. Scheele's master taught him such methods, and in addition instructed him in the use of the chemical symbols in vogue at that date; these he afterward freely employed in his manuscripts, and this renders them exceedingly difficult to decipher.

It was only when, as stated by Nordenskiöld, through Gahn he came into close relation with Bergman—a connection which began in a misunderstanding and coolness, but which developed into a friendship—that Scheele continued to gain steadily in reputation. After taking over the pharmacy at Koping in 1775, he was able to devote himself more closely to scientific work, and with still more brilliant results. The records of his researches followed one another rapidly in the "Transactions of the Stockholm Academy," into which he had been received as "Studiosus Pharmaciæ" in 1775. In 1777 he published the results of his investigation on air, oxygen, combustion and respiration at Upsala and Leipzig in a volume entitled "Chemische Abhandlung von der Luft und dem Feuer" ("A Chemical Essay on Air and Fire"). After his early death at barely forty-four years of age, his collected works were published in two volumes in German by S. F. Hermbstädt (Berlin, 1793), under the title, "Sämmtliche Physische und Chemische Werke." The Latin edition by Schaefer had appeared four years previous.

Altho the results of his principal investigations will be discussed further on, it is important to mention here that to Scheele is due the first knowledge of chlorine and of the individuality of manganese and baryta. He was an independent discoverer of oxygen, ammonia and hydrochloric acid gas. He discovered also hydrofluoric, nitrosulphonic, molybdic, tungstic, and arsenic acids among the inorganic acids; and oxalic, citric, tartaric, malic and mucic among the organic acids. He isolated glycerin and milk-sugar; determined the nature of microcosmic salt, borax, and "Prussian blue," and prepared hydrocyanic acid. He demonstrated that plumbago is nothing but carbon associated with more or less iron, and that the black powder left on solution of cast iron in mineral acids is essentially the same substance. He ascertained the chemical nature of sulphuretted hydrogen, discovered arsenuretted hydrogen, and the green arsenical pigment which is associated with his name. He found new processes for preparing gallic acid, ether, powder of algaroth, phosphorus, calomel, and "magnesia alba." His services to quantitative chemistry included the discovery of ferrous ammonium sulphate, and of the methods still in use for the analytical separation of iron and manganese, and for the decomposition of mineral silicates by fusion with alkaline carbonates.

The greatest work of the life of Scheele, however, was his memoir on "Air and Fire," which appeared in 1777, and which, on account of its relations to the chemical theory of that time, attracted universal attention, and was translated into English, French and German. The

chief part of the experimental material for this work, as is proved by the correspondence and laboratory journals published in 1892 by Nordenskiöld, was collected partly in Malmo and Stockholm—that is, before the autumn of 1770, and partly during the earlier portion of his stay in Upsala—that is, prior to 1773. These dates are important in view of Scheele's relations as a discoverer to Priestley and Lavoisier. A number of circumstances, and more especially the dilatoriness of the publisher Swederus, retarded the appearance of the book. From the letters to Gahn it appears that the manuscript was sent to the printer toward the close of 1775, but nearly two years elapsed before the work was made public. Scheele, in several of his letters, laments over the delay.

In August, 1776, he wrote to Bergman: "I have thought for some time back, and I am now more than ever convinced, that the greater number of my laborious experiments on fire will be repeated, possibly in a somewhat different manner, by others, and that their work will be published sooner than my own, which is concerned also with air. It will then be said that my experiments are taken, it may be in a slightly altered form, from their writings. I have to thank Swederus for all this." However, no imputation of plagiarism was ever brought against Scheele. The whole conduct of his life was proof indeed against even a suspicion of unfair dealing. He was exceedingly unselfish and veracious. To quote Thorpe, "With all Priestley's candor and sense of rectitude, he had Cavendish's indifference to fame and his contempt for notoriety. It can hardly be doubted, however, that had Scheele's work appeared in 1775 he himself would have occupied a still higher position in the estimation of his contemporaries, and that it would not have been left to posterity to assign him his true place in the history of scientific discovery." He further expresses the following appreciation:

"It is impossible to read this, or indeed any other of Scheele's memoirs, without being impressed by his extraordinary insight, which at times amounted almost to divination, and by the way in which he instinctively seizes on what is essential and steers his way among the rocks and shoals of contradictory and conflicting observations. But surmises, as Scheele himself said, cannot determine anything with certainty. It must be admitted that he was wanting in the faculty of coördination, grasp of principle, and power of generalization that so strikingly characterize Lavoisier; and his greatest investigation, while it testifies to his genius as an experimentalist, reveals, no less clearly, his weakness as a theorist. But when every legitimate deduction has been made, Scheele's work, with all its shortcomings and limitations, stamps him as the greatest chemical discoverer of his age. His story constitutes, indeed, one of the most striking examples of what may be achieved by the diligent cultivation of a single natural gift."

CHAPTER VIII

THE DAWN OF CHEMISTRY

ALTHO the services of the chemists whose investigations did most toward building up the chemistry of gases have been referred to, yet the influence of this work in shaping chemistry was so great that discussion of pneumatic chemistry and its relations to the phlogistic theory, in more detail, is necessary. Boyle, ingenious though he was, was unable to fathom the mystery of atmospheric air. His views regarding it are succinctly stated by him in his "Memoirs for a General History of the Air," and in the same work he sums up the views of the ancients. His words are:

> "The Schools teach the air to be a warm and moist element, and consequently a simple and homogeneous body. Many modern philosophers have, indeed, justly given up this elementary purity in the air, yet few seem to think it a body so greatly compounded as it really appears to be. The atmosphere, they allow, is not absolutely pure, but with them it differs from true and simple air only as turbid water from clear. Our atmosphere, in my opinion, consists not wholly of purer aether, or subtile matter which is diffused thru the universe, but in great number of numberless exhalations of the terraqueous globe; and the various materials that go to compose it, with perhaps some substantial emanations from the celestial bodies, make up together, not a bare indetermined feculancy, but a confused aggregate of different effluvia."

His researches, however, show a marked advance over those of van Helmont in the mode in which he collected gases and worked with them; at the same time neither he nor his contemporaries felt quite sure whether carbonic acid and hydrogen, whose characteristic properties he was acquainted with, differed materially from atmospheric air. In fact, the idea that gases were simply atmospheric air with various admixtures, had become fixed in the minds of chemists. The experimentalist Stephen Hales, for example, discovered gases and prepared them in a more or less pure state, but had no theory to guide him, and concluded that it was possessed of "a chaotic nature," since he failed to recognize his gases as different kinds of matter, but regarded them all as modified air.

Black's account of "fixed air" and its properties is the first example of a clear and logical series of experimental researches, where nothing was taken for granted, but everything was made the subject of careful quantitative measurement. It was not long since Hales had announced air to be a chaotic mixture of effluvia. Black showed that common air contains a small amount of "fixed air," and that "fixed air" must be considered as a fluid differing in many of its properties from common air, especially in its being absorbed by quicklime and by alkalies. It must be remembered that at that time carbon was not recognized as an element; and hence, tho Black knew that "fixed air" was a product of the combustion of charcoal, he did not attribute it to the union of carbon with oxygen.

Black held that the change from chalk to lime consists only in the withdrawal of "fixed air," and he adduced in proof the changes in weight accompanying the change from chalk to lime and back again:

"A piece of perfect quicklime, made from two drams of chalk, and which weighed one dram and eight grains, was reduced to a very fine powder, and thrown into a filtrated mixture of an ounce of a fixed alkaline salt and two ounces of water. After a slight digestion, the powder, being well washed and dried, weighed one dram and fifty-eight grains. It was similar in every trial to a fine powder of ordinary chalk."

The changes referred to are:

$$\text{chalk heated} = \text{lime} + \text{fixed air}$$
$$CaCO_3 = CaO + CO_2$$
$$\text{lime} + \text{fixed alkali} = \text{chalk} + \text{caustic alkali}$$
$$CaO + K_2CO_3 = CaCO_3 + K_2O$$

The methods of collecting gases had improved considerably since the times of Hales. Air was ascertained to be a fluid capable of measurement, which possessed weight, and which could be transferred from one vessel to another, just like all other fluids. The apparatus which Black, Priestley, Bergman, and Scheele employed, and those which we use at the present time, gradually developed themselves from that of Hales. Joseph Priestley was the first to describe the collection of gases over mercury, and by this means he succeeded in discovering gaseous ammonia, hydrochloric acid, silicon fluoride, and sulphurous acid—gases which had been overlooked so long as water was employed in the collecting vessels. As mentioned before, Scheele is now known to have anticipated Priestley in the isolation of some of these gases, as well as of nitric oxide and sulphuretted hydrogen (hydrogen sulphide). These investigations, along with the recognition of Cavendish that hydrogen is a peculiar gas, and the supplemental researches of Bergman and Black on carbonic acid, are to be emphasized as be-

ing particularly noteworthy, since they helped to do away with many misconceptions and errors.

The discovery of so many gaseous substances of such different character naturally roused the chemical world. The properties of each gas were carefully studied; and, after Mayow's researches, and especially after the more exact determination conducted by Cavendish, the density was taken as the criterion of one gas differing from another and from atmospheric air. Due attention was also given to the greater or lesser absorption of gases by water, as a distinct test for some of them; Bergman, for instance, determined with fair accuracy the solubility of carbonic acid in water. However, the exact composition of gaseous bodies remained unknown during this period, great uncertainty prevailing even about the simplest of them, until Lavoisier had pronounced his opinion as to the elementary nature of oxygen and hydrogen. But this could not be otherwise, so long as phlogiston was believed to be present in most gases. Hydrogen was thought to be identical with phlogiston by many chemists, soon after the middle of the eighteenth century, Cavendish and Richard Kirwan setting the precedent for this; others looked upon coal as being rich in phlogiston, if not as the latter itself; and often confused opinions were expressed concerning the composition of carbonic acid, carbonic oxide, nitric oxide, sulphurous acid, sulphuretted hydrogen, and other gases, these opinions being made to conform with the views of the phlogistic doctrine prevalent at that time.

Of greater importance than these views upon the constitution of the gases just named were the long unsettled questions, "Is atmospheric air a simple or a compound body, and—if the latter—what are its constituents or ingredients?" These questions were solved experimentally by chemists belonging to the phlogistic era, more particularly by Scheele and Priestley; but it was left to Lavoisier to interpret their observations correctly.

The first observation which assisted in overthrowing the old assumption of air being a simple substance, was the deportment of an enclosed volume to a burning body and to metals heated in it. The alchemists had asserted that when a substance is burned in the air it is separated or analyzed into things simpler than itself. The acute Boyle had said the process is not necessarily a simplification; it may be, and certainly sometimes is, the formation of something more complicated than the original substance, and when this happens, the process often consists in the fixation of "the matter of fire" by the burning substance. He was led by his investigations in this direction to the assumption that one ingredient of the atmosphere was necessary to respiration and combustion, and that the increase in weight during the calcination of metals was due to a ponderable firestuff. He remarked that,

"It will not be irrational to conjecture that multitudes of these fiery corpuscles, getting in at the pores of the glass, may associate themselves with the part of the mixt body whereon they work, and with them constitute new kinds of compound bodies, according as the shape, size and other affections of the parts of the dissipated body happen to dispose them. . . . I have been induced to think that the particles of an open fire working upon some bodies may really associate themselves therewith; and add to the quantity." (Boyle, "The Sceptical Chymist," 1661.)

He was unable to isolate this ingredient, however.

Stahl paid no attention to the change in weight resulting from calcination—a position which was taken also by many later phlogistonists, who either regarded such a change as accidental or advanced crude explanations of it. Johannes Juncker, for example, pointed out that the metallic "calces" were denser than the metals, and consequently heavier—decidedly an incorrect statement, as Boyce had already demonstrated in certain cases that the "calces" were specifically lighter than their corresponding metals. Equally ridiculous was the assumption that the phlogiston which escaped in calcination possessed a negative weight, and therefore that the end product was the heavier.

In 1630 Jean Rey published a series of essays entitled: "Essays of Jean Rey, Doctor of Medicine, on the Researches of the Cause owing to which Tin and Lead increase in Weight when they are calcined."

> "Now I have made the preparations, nay, laid the foundations for my answer to the question of the sieur Brun, which is, that having placed two pounds six ounces of fine English tin in an iron vessel and heated it strongly on an open furnace for the space of six hours with continual agitation and without adding anything to it, he recovered two pounds, thirteen ounces of a white calx; which filled him at first with amazement, and with a desire to know whence the seven ounces of surplus had come. And to increase the difficulty, I say that it is necessary to enquire not only whence these seven ounces have come, but besides them what has replaced the loss of weight which occurred necessarily from the increase of volume of the tin on its conversion into calx, and from the loss of the vapours and exhalations which were given off. To this question, then, I respond and sustain proudly, resting on the foundations already laid, 'That this increase in weight comes from the air, which in the vessel has been rendered denser, heavier, and in some measure adhesive, by the vehement and long-continued heat of the furnace: which air mixes with the calx [frequent agitation aiding] and becomes attached to its most minute particles: not otherwise than water makes heavier sand which you throw into it and agitate, by moistening it and adhering to the smallest of its grains.'"

The manner in which Rey arrives at his answer is not by any direct experiments on calcination, but rather by experiments and the reference to experiments of a purely physical nature, such as the discussion of the causes, like change of volume, which can, and of those, like heat, which cannot, produce change of weight. Thus he lays a sound foundation for his method. which is one of elimination, showing that none of the causes to which it had been usual to ascribe the observed increase in weight could be considered legitimate; that it could not be due to the giving up of heat of negative gravity, nor to the absorption of fire matter of positive weight, not to an increase in density, not to the absorption of soot or of anything else from the materials of the containing vessels. And so none is left unchallenged of all the possible modes of explanation save that of the fixation of the air.

Consequently, his conclusion that calcination of a metal probably consists in the fixation of particles of air by the metal, does not amount to a proof.

Mayow assumed that a "spiritus igno-aëreus" brought about combustion. According to him, the substance that is being calcined lays holds of this particular constituent of the air, which, however, he failed to isolate. Nevertheless, he approached closely to the correct interpretation of the phenomena in question, the real solution of which was brought forth after oxygen and nitrogen had been prepared with success.

Nitrogen was first isolated by Scheele, but Daniel Rutherford, who discovered it independently in 1772, preceded Scheele in publication. Rutherford removed the oxygen from ordinary air by combustibles such as charcoal, phosphorus, or a candle; and having got rid of the carbon dioxide, in those cases when it was formed, by alkali or lime, he obtained a residue, now known as nitrogen. His view of the nature of this gas, in the phlogistic language of the time, was that the burning bodies had given up some of their "phlogistic material" to the air, which was thus altered. Nitrogen was "phlogisticated air," even tho incombustible; hydrogen, too, was phlogisticated air, but air produced by the union of pure phlogiston with atmospheric air. The step taken by Rutherford, under Black's guidance, was an advance, though not a great one, in the development of the theory of the true nature of air. It followed from Scheele's, as well as Rutherford's, observations that this new gas, which was a non-supporter of either respiration or combustion, must be one of the ingredients of atmospheric air. The other was discovered by Scheele and Priestley.

It should be mentioned here that passages in early works suggest the possibility of a much earlier acquaintance with oxygen gas. Hoefer, in his "Histoire de la Chimie" (Vol. II, p. 271), claims to discover traces of a knowledge of oxygen gas in the writings of Zosimus, a Greek writer on alchemy, who lived in the third or fourth centuries.

In a manuscript preserved in the National Library of Paris, entitled "Zosimus the Panopolitan on the Sacred Art of making Gold and Silver," this passage occurs: "Take the soul of the copper, which is borne upon the water of mercury, and disengage an aëriform body ('soma pneumatikon')." Hoefer states that here we have indications of the production of a gaseous body by means of a red substance (the soul of copper) which floats on the surface of liquid mercury; if this substance is red oxide of mercury, the "aëriform body" must have been oxygen.

Moreover, in Campbell's "Hermippus Redivivus; or the Sage's Triumph over Old Age and the Grave," which was published in London in 1749, the following statement occurs: "I could mention another preparation from the vital part of the air itself, which is a great secret among these philosophers, and is perhaps the 'white dove' so often mentioned in the writings of Philalethes, of which, thus much is certain, that when the air is once despoiled of this principle, it is no longer fit for animal respiration, and it was by a contrivance of this kind that the famous Cornelius Drebbel made that liquor, which supplied the place of air in the machine he contrived for carrying on a kind of submarine navigation. This medicine, which is, as I have said, extracted from the air, is whiter than the snow, colder than ice, and so volatile that if a quantity of a nutmeg be exposed to the air it is absorbed thereby in the space of a few seconds." As Bolton has remarked, this passage refers "in an unmistakable manner to the preparation of oxygen and its property of supporting life." Drebbel (1572-1634) appears to have rowed in a boat under water in the Thames River for a distance of about eight miles, and his employment of compressed oxygen gas, if it may be so interpreted, must have been about the beginning of the seventeenth century.

Scheele prepared oxygen by heating black oxide of manganese with sulphuric or arsenic acid, and also from nitrates, and from the oxides of mercury and silver, and noted its characteristics very clearly. Priestley, who also observed the gas at about the same time, without, however, recognizing its peculiar nature, first isolated it for certain on August 1st, 1774, by heating red oxide of mercury; and as he published his results earlier than Scheele, he has generally been regarded as the first discoverer of oxygen. Both observed that this gas was capable of supporting combustion and respiration in an intensified degree. Priestley named it "dephlogisticated air," and Scheele at first "aer vitriolicus," later "fire-air," and also "life air."

The discovery of oxygen enabled both Scheele and Priestley to recognize air as being a mixture of two kinds of gas; Priestley calls nitrogen "Phlogisticated air," and Scheele terms it "spent air." Priestley employed saltpeter gas (nitric oxide) as an absorbent for oxygen, while Scheele made use of phosphorus, hydrate of protoxide

of iron, mixtures of iron and sulphur, and moist iron filings. Both made the important observation that, upon burning a candle in an enclosed volume of air, exactly as much "fixed air" (carbon dioxide) was generated as oxygen had vanished.

Notwithstanding all this, they did not arrive at the correct explanation of combustion, respiration and calcination, whose analogy to one another they clearly saw.

The breathing of animals and the burning of substances were supposed to load the atmosphere with phlogiston. Priestley spoke of the atmosphere as being constantly "vitiated," "rendered noxious," "depraved," or "corrupted" by processes of respiration and combustion; he called those processes whereby the atmosphere is restored to its original condition (or "depurated," as he said), "dephlogisticating processes." As he had obtained his "dephlogisticated air" by heating the calx of mercury, Priestley was forced to suppose that the calcination of mercury in the air must be a more complex occurrence than merely the expulsion of phlogiston from the mercury; for, if the process consisted only in the expulsion of phlogiston, how could heating what remained produce exceedingly pure ordinary air? It seemed necessary to suppose that not only was phlogiston expelled from mercury during calcination, but that the mercury also imbibed some portion, and that the purest portion, of the surrounding air. Priestley did not, however, go so far as this; he was content to suppose that in some way, which he did not explain, the process of calcination resulted in the loss of phlogiston by the mercury, and the gain, by the dephlogisticated mercury, of the property of yielding exceedingly pure or dephlogisticated air when it was heated very strongly.

Consequently, the path distinctly indicated by his own observations was left for another to tread. It was Lavoisier who was destined to do this, as he easily threw aside the trivial phlogistic misconceptions that he cherished at the commencement of his scientific career. The others, indeed, supported a contradictory explanation of combustion and analogous processes, in order to remain loyal to the phlogistic doctrine. But that it was Priestley and Scheele, who, by their exhaustive investigations on oxygen and the part which it played in the processes mentioned, furnished the experimental material for the correct interpretation of these, and not Lavoisier, is beyond all question. It remained for the latter, however, to give the correct explanation of combustion; calcination and similar processes.

Among the treatises on air which appeared during this period, other than those mentioned, were Bohn's "Meditationes physico-chymicae de aëris in sublunaria inflex" (1685); Arbuthnot's "An Essay concerning the Effects of Air on Human Bodies" (1751); and Cavallo's "A Treatise on the Nature and properties of Air and other permanently elastic Fluids" (1781).

In order to appreciate the advances which the chemical ideas of the Phlogistic Period showed upon those of the periods already discussed and to understand the connection which exists between the theoretical views of the phlogistonists and those of the chemists of the Modern Period, it is necessary to become acquainted with their views regarding elements, chemical compounds and chemical affinity.

Boyle's definition of an element—that it is any substance which cannot be further decomposed—was one of great significance for the whole of natural science. He also considered that the elements attainable by chemical investigation were not the ultimate constituents of matter. Nevertheless, his contemporaries and successors, failing to appreciate these views, exhibit a tendency to revert to the alchemistic elements and even to those of Aristotle. For instance, Lefevre, author of a treatise on theoretical chemistry, and Lemery classified earth and water with the three elements of Basilius Valentinus and Paracelsus, while Becher held to those three under other names—the "vitrifiable," the "inflammable," and the "mercurial" earths—and added water to the list.

According to Stahl's views, sulphur consists of sulphuric acid and phlogiston; and a metal, of its metallic "calx" (oxide) and phlogiston. Therefore, the phlogistonists assumed that all products of calcination and combustion (acids and oxides) were elements, in which class of substances they also classed phlogiston itself. These erroneous assumptions kept back a knowledge of the true elements, and only after it was clearly demonstrated that instead of the escape of phlogiston, the absorption of oxygen must be allowed, and in place of the assimilation of phlogiston the removal of oxygen, did that extraordinary genius Lavoisier bring light into the confusion which prevailed by his brilliant ideas and observations.

A better understanding of the composition of substances was gained by analytical chemistry, which was gradually developing during this period; but altho certain constituents of compounds could be identified and distinguished from one another, yet the proportions by weight in which substances combined were not considered, and consequently the real development of the term "chemical compound" was reserved for the period of quantitative chemistry.

The chemists of the Phlogistic Period were forced to draw their conclusions concerning the composition of substances from analogy, notwithstanding which fact, however, several contributed materially to an insight into the nature of chemical compounds. Robert Boyle, for example, recognized the dissimilarity of such substances to elements, while he, Mayow, and Boerhaave stated that the characteristic properties of substances which combine chemically disappear after such combination, nothwithstanding the fact that they are still present in the compound formed. Acids, salts and oxides ("calces") were,

however, regarded as being of similar composition; and, u recognized that salts were produced by the combination of a bases—an achievement of this period—the term "salt" was promiscuously. Stahl, for instance, applied the term to acids kalies as well as to salts proper, and considered that salts we up of an earth and water.

In 1745, Rouelle rendered a great service to the study of sal the diffusion of knowledge respecting this class of compounds i attractive lectures. He defined salts as the products of the union of acids with bases, and distinguished normal, acid and basic salts, and showed their action on vegetable dyes. Yet he confounded many salts with acids, and could not throw off the old idea that the vitriols and other metallic salts consisted of metal and acid. Bergman demonstrated the falsity of this assumption when he proved that it is the metallic calces and not the metals themselves which combine with acids to form salts. After the time of Rouelle, solubility in water and taste were no longer regarded as characteristics of salts, inasmuch as he classed several insoluble compounds among them.

Important work on chemical affinity was contributed during this period, notwithstanding the fact that the old assumption that those bodies have an affinity for one another which have something in common—that affinity is governed by this, remained a mental fixture with speculative chemists even into the eighteenth century. The term "affinitas," used by Albertus Magnus to express this idea, presupposed the similarity of substances which interact chemically. As is generally the case, another idea evolved itself, and has lived until the present time, side by side with the first, to which it is exactly contradictory; this considers union as dependent upon contrast, on polar difference, on an effort to fill up a want. This contrary idea found a devoted exponent in Boerhaave, who maintained that it is unlike substances which show the greatest tendency to combine with each other. His influence secured the general adoption of his views by chemists.

After the time of Glauber, and particularly after that of Boyle, much attention was paid to the processes in which the forces of affinity show themselves. Cases of so-called simple elective affinity ("attractio electiva simplex," a term which originated with Bergman) were interpreted correctly by both the chemists just named, and also by Mayow; for instance, the expulsion of ammonia from salmiac by fixed alkali, by the assumption that the attraction of the latter for hydrochloric acid was greater than that of this acid for the ammonia (fluchtiges Laugensalz). Observations of this kind on the expulsion or precipitation of bases or acids from salts, by substances endowed with stronger powers of affinity, soon caused chemists to solve the order in which analogous bodies were separated from their compounds

The observations on the precipitation of metals and on the of various acids from salts by means of sulphuric and nitric ıong others, may have tended in an especial degree to make ; different strengths of affinity in analogous bodies.

, the founder of the phlogistic theory, contributed important ›n affinity. He attempted (1720) to classify the effects of af- oy arranging similar substances in a series in the order in which :xpel one another from a compound: "The following mechanical experiment may serve as an example. Dissolve silver in nitric acid, it will take up the silver and appear as a light liquor; into the clear and transparent liquor throw thin strips of copper foil, the nitric acid will dissolve these and will drop the silver in the form of a powder; pour this clear green solution on to lead foil, it will be attacked and the copper previously dissolved will be dropped; pour off the clear solution and pour it on to zinc, it will dissolve the zinc and allow the previously dissolved lead to drop; into this clear solution put chalk; it will be dissolved and the zinc dropped; then to this solution add spirits of urine, which will combine with it, releasing the chalk; and finally drop in lye, the solution will take it up and allow the volatile salt to go."

Geoffroy used such a classification as the basis of his tables of affinities, "Tables des Rapports" (1718), an arrangement destined to become very popular. The principle was to arrange similar substances so that the one following was always expelled by the one preceding from combination with the one heading the list. When thus represented, Stahl's example just quoted becomes: Nitric Acid: potash, ammonia, lime, zinc, lead, copper, silver.

But yet another most important discovery concerning the action of affinity is due to Stahl. He recognized the fact that a reaction occurring at one temperature in one direction could be reversed at another temperature; that at ordinary temperatures calomel is decomposed by silver, while under the influence of heat silver chloride is decomposed by mercury. Such reciprocal reactions led to the suggestion to prepare tables of affinity for medium and high temperatures, both for wet and dry (*i.e.*, fusion) reactions. Bergman made the attempt in 1775 to work out this proposal of Baume's by investigating the mutual behavior of a very large number of compounds, with the result that the doctrine of chemical affinity was materially advanced, in so far as this was possible by such empirical work.

Bergman's work on affinity was published in his "Opuscula physica et chemica." His views may be summarized as follows: (1) There is a sequence in the magnitude of the elective affinities of a series of substances toward one with which they all combine, and this is manifested by the fact that the one possessing the greater affinity, expels from the combination the one possessing the lesser affinity. (2) This

order is constant under each of the two different conditions of interaction in the moist and dry way respectively, but differs under these two distinct conditions. (3) The substance of lesser affinity is completely expelled by that of greater affinity, subject, however, to the possibility that the mass of the expelling substance may have to be very much greater than that required for simply replacing the expelled substance in the combination. (4) It is impossible to reverse such a reaction.

The following abstract from the table of Bergman on affinity will indicate the principles upon which it was based:

Sulphuric acid.

Wet way.	Dry way.
Baryta	Phlogiston
Potash and soda	Baryta
Ammonia	Potash
Alumina	Soda
Zinc oxide	Lime
Iron oxide	Magnesia
Lead oxide	Metallic oxides
Copper oxide	Ammonia
Mercury oxide	Alumina
Silver oxide	

Potash.

Wet way.	Dry way.
Sulphuric acid	Phosphoric acid
Nitric acid	Boracic acid
Hydrochloric acid	Arsenic acid
Phosphoric acid	Sulphuric acid
Arsenic acid	Nitric acid
Acetic acid	Hydrochloric acid
Boracic acid	Acetic acid
Sulphuric acid	
Carbonic acid	

In the table the order from top to bottom gives the relative displacing power. Thus in combination with sulphuric acid, where the action takes place in aqueous solution, baryta is represented as displacing any of the substances placed below it, and so with potash, ammonia, etc. Where the dry substances are subjected to heat, the order is changed somewhat.

It was recognized then that the strength of affinity varied with the temperature. This is the "attractio electiva simplex" of Bergman.

He recognized also an "attractio electiva duplex." Macquer made use of the term "affinitas reciproca," where two bodies seemed to have nearly the same strength of affinity for a third substance, one replacing the other under slightly changed conditions—a partial recognition of the fact that affinity is dependent upon other conditions besides temperature.

This should have sufficed to show the unreliable character of the various tables offered, but chemists were slow to give them up. Nor did they value at its true worth the remarkable work of Berthollet in the next period and his conclusion that the action of affinity was proportional to the masses of the interacting substances. This, properly understood, entirely did away with all such tables, for a body with lesser affinity could displace one of greater, provided it was present in a sufficiently greater mass.

Among the chemists of this period who wrote treatises on the subject of affinity may be mentioned Limbourg (1761), Marherr (1762), Wenzel (1777), Keir (1778), Wiegleb (1780), Elliot (1786), Guyton de Morveau (1786), and Schmieder (1799).

The growth of applied chemistry during the Phlogistic Period is next to be recorded. This division of the science was especially assisted in its development by that indispensable branch, analytical chemistry, in which notable advances were made.

Qualitative chemical analysis, which had its beginning in the iatrochemical period, was developed by the investigations of Boyle, Hoffmann, Marggraf, Scheele and Bergman. The first named introduced the word "analysis" for those chemical reactions by which individual substances could be detected in the presence of one another, and considerably advanced the analytical examination of substances in the wet way. He employed reagents to distinguish the important classes of compounds, and the systematic use of plant juices as indicators for the detection of acids, bases and neutral substances originated with him. For this purpose, he used the coloring matters in the juices of litmus, violets and corn-flowers. Among the other reagents he introduced may be mentioned solutions of calcium and silver salts for the recognition of sulphuric and hydrochloric acids respectively, infusions of oak leaves or gall nuts for the detection of solutions of the salts of iron, and volatile alkaline salt for the recognition of copper salts. He recognized ammonia by the white cloud that resulted when it came in contact with fuming acids, such as hydrochloric or nitric acids.

Hoffmann busied himself in analytical chemistry mainly with the investigation of mineral waters. He examined many samples, and showed that they contained carbonic acid, iron, common salt and salts of magnesia and lime. He furnished valuable information as to the methods of testing for these substances, and also indicated many characteristics of mineral waters. The "Tabelle über einige 40 Mineral-

wässer" was an important contribution by Carl A. Hoffmann (1789).

Marggraf, besides proving that gypsum consisted of lime and sulphuric acid, and that the latter was also a constituent of heavy spar, made use of the different colorations which the salts of soda and potash impart to a flame as a means for their recognition, and employed a solution of prussiate of potash as a test for iron.

Scheele made many valuable observations in analytical chemistry. He it was who perceived the difference between soluble and insoluble silicic acid, and effected the separation of iron and manganese by acetic acid, in addition to independently observing the flame colorations of salts of soda and potash, and explaining the difference between the inner and outer flames of the blowpipe, a piece of apparatus which was introduced into chemistry by Gahn, Cronstedt and Bergman. The latter was indebted to Scheele for many observations, but was more systematic than his contemporary. He suggested the use of sublimate, liver of sulphur, and sugar of lead as reagents; of hydrochloric acid or carbonate of potash to open up ores; and of methods for the separation of salts and the estimation of precipitates. The tests he employed for the recognition of sulphuric, hydrosulphuric, carbonic, arsenious and oxalic acids, and of lime, baryta and copper, are still in use.

Bergman was, to quote von Meyer, "probably the first to proceed on the principle that an element should not be itself isolated and estimated according to its own weight, but separated in the most convenient form as an insoluble precipitate—*e.g.*, lime earth as oxalate of lime, and sulphuric acid as sulphate of baryta," in the determination of the weights of metallic precipitates. This procedure, in conjunction with the endeavors of Marggraf, Homberg, Scheele and Black, to take the proportions by weight into account—in other words, to determine the quantity of a substance or substances present in a solution—furnished important preparatory work for the quantitative investigations of the next period.

In the analysis of gases, the most noteworthy work of the period was done by Cavendish, who made a determination of the amount of oxygen in the air by exploding with hydrogen. He found that the oxygen amounted on the average to 20.85 per cent., a result which is only 0.05 per cent. short of the mean as determined at the present day. It was learned that carbonic acid and oxygen could be estimated volumetrically by the use of absorptives: caustic potash was used for the absorption of the former, and phosphorus for that of oxygen.

Mainly owing to the efforts of such investigators as Boyle, Kunckel, Marggraf and Duhamel du Monceau, technical chemistry made considerable progress during the Phlogistic Period.

In metallurgy, correct explanations of many processes were brought out, although in general it may be said that the methods of extracting

metals from their ores underwent little improvement. In the manufacture of iron and steel, however, some material changes were made as a result of the investigations of Bergman, Gahn, Rinman and Rene Reaumur. The latter's work, "L'Art de convertir le fer forge en acier et l'art d'adoucir le fer fondu, ou de faire des ouvrages de fer fondu aussi fin que de fer forge," published in Paris in 1722, brought the author a pension of 12,000 francs from the Duke of Orleans, because of the improvements it effected in the manufacture of cast iron and steel. An account of Reaumur's method of softening cast iron was also embodied in Horne's "Essays Concerning Iron and Steel," a work of useful observations published in London in 1773. Duhamel improved the manufacture of brass, and Marggraf introduced a more satisfactory method of preparing zinc from calamine.

A valuable treatise by Kunckel on the ceramic art and glass-making appeared in 1689. This work was entitled "Ars vitraria experimentalis," and contained Neri's "Arte vitraria," with additions by Kunckel and others. After the introduction of the importation of chinaware, many attempts were made to imitate this true porcelain. In this, Böttger (1685-1719) made the first advance in 1709, altho it is now known that a porcelain of soft paste was made at Florence as early as 1580. Böttger first made a red ware, but eventually, by employing kaolin, he made a true porcelain at Meissen. The process of manufacture remained a secret, however, and it was not until it was solved at Sevres in 1769 by the experimental work of Reaumur and other chemists that the manufacture spread.

In England, porcelain appears to have been experimentally manufactured at Fulham, by Dwight, as early as 1671; but it was not produced in quantity until about 1730, when works were established at Bow. In this connection, Higgins' "Experiments and Observations made with the view of Improving the Art of composing and applying Calcareous Cements" (1780) should be mentioned. This treatise contained the results of valuable experimental investigations on the induration and strength of cements.

Two works of great aid to the dyer—Macquer's "L'Art de la teinture en soie" (1763), and Hellot's "L'Art de la teinture des laines et etoffes de laine" (1750, 1786)—in that they contained speculations upon the manner in which dyeing operations are carried out, appeared during this period. Stahl, Hellot and Macquer divided dyes into two classes, viz., those capable of being fixed on cloth without the aid of mordants, and those requiring the use of such agents, and in 1794, Bancroft distinguished these divisions as adjective and substantive dyes. Prussian blue was discovered by Diesbach in 1710.

Sulphuric acid, the manufacture of which constitutes one of the most important branches of modern technical chemistry owing to the great variety of purposes for which it is required, was first manufac-

tured on a large scale by a quack physician of the name of Ward, about the middle of the eighteenth century. For this manufacture, he employed glass globes of about 40 to 50 gallons capacity; a small amount of water having been poured into the globe, a stoneware pot was introduced, and on this a red-hot iron ladle was placed. A mixture of sulphur and saltpeter was then thrown into this ladle, and the vessel was closed. The vapors evolved were absorbed by the water, and sulphuric acid costing from 1s. 6d. to 2s. 6d. per pound was obtained. Roebuck of Birmingham was the first to suggest the use of leaden chambers instead of glass globes. These leaden chambers were set up in Birmingham in 1746, and were worked intermittently; the continuous working of them is an achievement of the nineteenth century.

The manufacture of fuming sulphuric acid was first carried out at Nordhausen in the Harz, by heating roasted green vitriol, but was subsequently removed to Bohemia. Rouelle demonstrated that nitric acid could be concentrated by distillation with sulphuric acid. A number of improvements were made in the manufacture of this acid by Stahl and other chemists, but hydrochloric acid was not prepared in large quantities, as it was not employed technically. As early as 1670, an artist, Henry Schwanhard, prepared hydrofluoric acid for etching figures on glass, and it is probable that his preparation was the same as that known to some artists as a secret in 1721, and published by Weygand in 1725.

The alkalies and their carbonates were obtained just as in ancient times, viz., from the ashes of plants, incrustations on the soil, and carbonized tartar. However, it was shown by Duhamel and other chemists that common salt could be converted first into sulphate of soda, and finally into carbonate of soda. A description of such a process is contained in the "Description de Divers Procedes pour Extraire la Soude du Sel Marin," published by the "Imprimerie du Comite de Salut public" in 1795. Duhamel also introduced suitable methods of preparing starch and soap, and improved the processes of manufacturing sal ammoniac and sugar. His "L'Art de raffiner le sucre" (764) was held in high esteem in this period. Marggraf's discovery of cane sugar in the juice of the red beet has been referred to; it only remains to say that it laid the foundation for the now enormous and important beet sugar industry.

The knowledge of the chemical elements and compounds was enlarged to a remarkable degree in the Phlogistic Period, and the discoveries made and facts learned afterward became of great technical importance. Six new elements—chlorine, phosphorus, manganese, cobalt, nickel and platinum—were added to the ones already known.

Phosphorus was obtained by Brand, a Hamburg alchemist, in 1669, by distilling the residue from evaporated urine; he called it "cold fire," and in 1671 Johann Elsholtz, of Vienna, gave it the same name as the Bologna stone, or "phosphor," which was discovered about 1603. The discovery of phosphorus caused much excitement on account of its properties, but its preparation was kept secret, and it was only after many endeavors that Boyle and Kunckel discovered the method of obtaining it. The "phosphorus" described by Balduinus in 1675 is thought to have been dry calcium nitrate, while that discovered by Homberg in 1693 was an oxychloride of calcium. Kunckel, in several treatises on phosphorus, gave an account of its discovery and contributed to a better knowledge of the element.

The first account of metallic manganese was given in the "De metallis dubiis" of Jacob Winterl and J. G. Kaim, which was published in Vienna in 1770. Gahn, however, is generally credited with its isolation, which he effected in 1774. Cobalt was discovered by Brandt in 1742, and the earliest full account of the metal is contained in Johann Gesner's "Historia cadmiæ fossilis metallicæ sive cobalti," which appeared the next year. Nickel was first prepared by Cronstedt in 1750. The observations of Arvidson on this interesting metal were published in 1775.

Platinum is first referred to in Don Antonio de Ulloa's "Relacion historica del viage a la America Meridonal" (1748). William Watson, an English chemist, was the first to examine the "Platina di Pinto," found in the Spanish West Indies by explorers, and his observations, along with Brownrigg's experiments on the metal, were published in the "Philosophical Transactions" of the London Royal Society in 1751. Watson's experiments were continued by Lewis in 1755, Macquer in 1758, and Marggraf in 1761. De Buffon asserted that platinum was an alloy of gold and iron, and von Milly considered that it contained these metals, together with mercury. Its elementary nature was not established to the satisfaction of all until the next period.

The knowledge of organic compounds was also considerably extended, and new fields for organic chemistry were opened up toward the close of the period. However, the real composition of all organic compounds was not ascertained until the time of Lavoisier.

Attempts were made by Reaumur in 1733, and Mathurin Brisson in 1768, to determine the amount of alcohol in aqueous solutions containing it from its specific gravity. An interesting treatise on wines, "Ueber die Verfälschung der Weine," was written by Friedrich Cartheuser in 1779. Frobenius (1730), Hoffmann, Pott, Antoine Baume (1757), and Cadet de Gassicourt (1775) investigated ether ("spiritus vini vitriolatus"), but until 1800 it was believed to contain sulphur. A

mixture of ether with alcohol, known as "Hoffmann's drops," and the compound ethers were used officially.

Scheele discovered, or first clearly distinguished, the important organic acids, showing that grapes contained one (tartaric acid) which differs from that found in lemons (citric acid); that another (malic acid) occurred in apples, and again a new one (oxalic acid) was detected in wood-sorrel. The latter he prepared by the oxidation of cane-sugar with nitric acid, and found that it differed from the one obtained by treating milk sugar with nitric acid (mucic acid). He also discovered lactic acid in sour milk, uric acid in bladder stones, and prussic acid by decomposing yellow prussiate of potash with sulphuric acid; and improved the methods of preparing gallic and benzoic acids. He showed that the latter forms a lime salt freely soluble in cold water, and therefore may be readily obtained by boiling gum benzoin with milk of lime, concentrating the filtrate and separating the acid by means of hydrochloric acid. On the other hand, he learned that malic, tartaric and citric acids formed insoluble salts with lime or lead oxide, by the aid of which substances they might be separated from other bodies in the fruit. He prepared the acids by decomposing their lime or lead salts thus obtained with sulphuric acid.

Formic acid was discovered by Wray in 1760, and was further investigated by Arfvidson and Cehrn in 1777. Its resemblance to acetic acid, which was now prepared in a pure form, was soon observed, and this produced some confusion. Marggraf proved that they differed.

Oils and fats were frequently investigated, and Scheele showed that they contained a common constituent, oelsüss, or the "sweet principle of oils." This is now known as glycerin, or glycerol. Scheele stated that it is related to sugar, not only because of its taste, but also on account of the fact that both substances yield oxalic acid in treatment with nitric acid. The importance of this discovery was not realized until a much later date.

Considerable progress was made during this period in medical and pharmaceutical chemistry, and many new medicines came into vogue. Among these were carbonate of ammonia, sulphate of potash, magnesia alba and sulphate of magnesia.

Among the text-books which appeared may be mentioned the following: the "Manuductio ad chamiam pharmaceuticam" of Rivinus (1690); Fick's "Chymicorum in pharmacopœia Bateana et Londinensi explicatio" (1771); von Ludolff's "Die in der Medicin siegende Chemie" (1750), and Baume's "Elements de Pharmacie Theorique et Pratique" (1672). The advances made in organic and medical chemistry prepared the ground for physiological chemistry, a branch which has been greatly developed in the most recent period.

CHAPTER IX

LAVOISIER—DISCOVERER OF COMBUSTION

It has been seen how far the development of chemical knowledge during the seventeenth century was influenced by Stahl's phlogistic theory—that this theory exerted a decided influence on the progress of chemistry, but that it was too elastic to give exact definitions to the tendency of investigation. It had, however, done good work, since it coördinated facts and developed unity of purpose, and served admirably as a period of preparation for the scientific experimental work of the era commencing with the discovery of oxygen by Scheele and Priestley—the Modern Chemical Period. For twenty years following this discovery a contest concerned mainly with the recognition of the experimental method was pursued. It had to do with the support of the method of observation under definite conditions as the foundation of all theoretic inferences and views, and with the subduction of the prejudices which had resulted from following the method which fostered speculation and the adaptation of observations, as far as possible, to the established system.

This short period of revolution (1774-1794) is rendered radiant by the reforms of one of the most remarkable men in the history of science, Lavoisier, who abolished old prejudices and masterfully applied scientific principles to the explanation of chemical phenomena. His combustion theory supplanted the doctrine of phlogiston—a change, it is true, that primarily only required the substitution of the words "addition of oxygen" for "withdrawal of phlogiston," but which eventually resulted in a complete transformation of all ideas concerning combustion, calcination and respiration, and consequently the views respecting chemical composition—a displacement which culminated in the conversion of the chemistry dominated by the dogma of Stahl into the antiphlogistic system, the "New Chemistry."

The Phlogistic Theory was deposed by the Theory of Oxygen, but, as Whewell has pointed out, "this circumstance must not lead us to overlook the really sound and permanent part of the opinions which the founders of the phlogistic theory taught." In this connection, we must not forget how much Lavoisier owed to his predecessors. He sifted and collated the facts handed down to him by the phlogistonists, and, mainly from the standpoint of the physicist, gave correct

explanations of many processes; but he made no independent chemical discoveries, and is honored not as a Scheele or Black, but as the founder of a new system based on his comprehensive and correct explanations of the observations of other investigators. Consequently, it may be said that Gallic patriotic bias prompted Wurtz to state in his "Histoire des Doctrines Chimiques" that "La chimie est une science française"—an assertion which was repeated twenty years later by Jagnaux. Since, however, chemistry only took rank as a science when quantitative work was made its basis, Lavoisier must be given credit above all others in having directed it into and along this road.

Antoine Laurent Lavoisier was born in Paris on the 26th of August, 1743. His father was wealthy and spared no expense on his education. In his twenty-first year Lavoisier obtained a gold medal from the Academy of Sciences for an essay on the most appropriate method of lighting the streets of Paris, but it was some years before he made definite choice of his subject. He published memoirs relating to geology and to mathematics, before the fame of Black's and Priestley's discoveries reached him and induced him to turn his attention to scientific chemistry.

By good business management he greatly added to his property and became a man of wealth. He lived well, giving dinners which were famed for their excellence and for the company gathered at them. This attracted attention to him and won for him some enemies whose influence was felt in the storm gathering against all that smacked of aristocracy. In addition, he was a fermier-général; and tho he brought about some reforms, some of his measures proposed to the Government were exceedingly unpopular, as, for instance, his plan for taxing Paris. Impeached under the Reign of Terror, he was condemned to death, and was executed, together with twenty-eight other fermiers-généraux, on the 8th of May, 1794.

In Lavoisier is seen a master mind, not only capable of devising and conducting experiments, but mainly of assimilating those of others, and deducing from them their correct significance. Altho his additions to the known chemical compounds were few in number, and cannot, as mentioned, be compared with those of Scheele or of Priestley, yet his reasoning in disproof of the phlogistic theory was so exact that it rapidly secured conviction, and laid the foundation for the new chemistry of the quantitative era. Hitherto exclusive importance had been attached to visible phenomena, but Lavoisier introduced a more exhaustive investigation of chemical reactions and the relations of quantity. The important work in which he recognized and explained the part played by oxygen in the process of combustion, calcination, and respiration embodies the chief investigations of his life, however, and in this lies his abiding service to science.

The earlier observations of Rey, Mayow, and others, who had attributed the increase in weight of the metals during their calcination to an absorption of air, contained only the first germs of the true explanation of these processes. From the year 1772 Lavoisier engaged in investigations bearing upon this subject, the first results of which he delivered in a sealed note to the French Academy on November 1st of that year. This note was to the following effect:

> "About eight days ago I discovered that sulphur, when burned, instead of losing weight, gains weight; that is to say, from one pound of sulphur much more than one pound of vitriolic acid is produced, not counting the moisture gained from the air. Phosphorus presents the same phenomenon. This increase of weight is due to a great quantity of air which becomes fixed during the combustion, and which combines with the vapors. This discovery, which I confirmed by experiments which I regard as decisive, led me to think that what is observed in the combustion of sulphur and phosphorus might likewise take place with respect to all the bodies which augment in weight by combustion and calcination; and I was persuaded that the gain of weight in calces of metals proceeded from the same cause. Experiment fully confirmed my conjectures. I effected the reduction of litharge in closed vessels with Hales' apparatus, and I observed that at the moment of the passage of the calx into the metallic state, there was a disengagement of air in considerable quantity, and that this air formed a volume at least a thousand times greater than that of the litharge employed. As this discovery appears to me to be one of the most interesting which has been made since the time of Stahl, I thought it expedient to secure to myself the property, by depositing the present note in the hands of the secretary of the Academy, to remain secret till the period when I shall publish my experiments.
>
> "LAVOISIER."

He was, however, in the same position as Mayow had been—that is, still in doubt as to which portion of the air caused this increase in weight, as to the air itself being a mixture of gases, and especially as to the nature of the process which occurred in the reduction of the litharge; he felt inclined to regard the generated gas (carbonic acid) as the fluid originally combined with the lead. This uncertainty was brought about by his giving little attention to the qualitative side of the chemical reactions.

In 1774, after repeating these and similar investigations, Lavoisier found his error with regard to the reduction of litharge, and furnished more elaborate details of his observations, especially of the calcination of tin. He began by considering the possible solutions of the

problem, and then investigated what changes really do occur, from which he inferred the cause. To quote from his "Œuvres":

"Thus then did I at the beginning reason with myself: if the increase in the weight of metals calcined in closed vessels is due, as Boyle had thought, to the addition of the matter of the flame and the fire which penetrate the pores of the glass and combine with the metals, then it follows that on introducing a known weight of metal into a glass vessel and sealing this hermetically, determining the weight exactly, and then proceeding to calcination by a charcoal fire—just as Boyle had done—and then finally after calcination, before opening it, again weighing the same vessel, this weight must be found augmented by that of the whole quantity of fire matter which had been introduced during calcination. But if, said I to myself, the increase in the weight of the metal calx is not due to the addition of fire matter nor of any other extraneous matter, but to the fixation of a portion of the air contained in the vessel, the whole vessel after calcination must be no heavier than before and must merely be partially void of air, and the increase in the weight of the vessel will not occur until after the air required has entered."

To test these theoretical considerations, Lavoisier selected the calcination of lead and of tin in sealed retorts. From two careful experiments with eight ounces of tin—similar ones with lead were unsuccessful—Lavoisier found that the increase in weight of the tin on calcination was practically identical with the weight of air which took the place of that absorbed during calcination. His conclusions were as follows:

"Summing up the results of the two experiments on tin just decribed, it seems to me impossible not to draw the following conclusions:

"First. In a given volume of air only a fixed quantity of tin can be calcined.

"Secondly. This quantity is greater in a large retort than in a small one.

"Thirdly. The hermetically sealed retorts, weighed before and after the calcination of the tin contained in them, showed no difference of weight, which evidently proves that the increase in weight of the metals arises neither from the fire matter nor from any other matter extraneous to the vessel.

"Fourthly. In all calcinations of the tin the increase in weight of the metal is sufficiently nearly equal to the weight of the air absorbed, to prove that the portion of the air which combines with the metal during calcination is of specific gravity approximately equal to that of atmospheric air."

Thus the problem he had undertaken had been solved by Lavoisier. He had ascertained the cause of the increase in the weight of metals

on calcination and had found it to be in combination with a certain portion of the air. And having proved before that sulphur and phosphorus on burning also increase in weight and absorb a large volume of air, Lavoisier must at that stage, as Freund remarks, be supposed to have established that combustion consists in combination with a portion of that atmospheric air, whereby the increase in weight on combustion is accounted for. However, he knew nothing as yet concerning the nature of the portion of air absorbed. In the time between the memoir on the calcination of tin and his next contribution to the subject of combustion, falls Priestley's discovery of a gas obtainable by the heating of red oxide of mercury, the investigation of the properties of this gas, and the recognition that it is a better supporter of combustion than ordinary air; Lavoisier learned of this new fact, and his next paper bears evidence of the manner in which he was helped thereby.

This paper, which was written in 1775, was entitled "On the Nature of the Principle which combines with Metals during their Calcination, and which increases their Weight." In this he described experiments showing that when metallic "calces" are converted into metals by heating with charcoal, a quantity of fixed air is expelled; and here for the first time he pointed out that "'fixed air' is a compound of carbon with the elastic fluid contained in the 'calx.'" He then described the preparation of oxygen by Priestley's process of heating red oxide of mercury ("mercurius precipitatus per se"), and showed that the red oxide, when heated with charcoal, exhibited the properties of a true "calx," inasmuch as metallic mercury was formed and a large quantity of "fixed air" was produced.

In 1776, Lavoisier observed that the combustion product of the diamond was composed of carbonic acid alone; and in his next paper, which appeared the following year, he dealt with the combustion of phosphorus; he recapitulated Rutherford's experiments, and showed that one-fifth of the air disappeared, and that the residue, to which he gave the name "mouffette atmosphérique," is incapable of supporting combustion. As mentioned, Rutherford named this residue "phlogisticated air," since he imagined it to have absorbed phlogiston from the burning phosphorus; Scheele, too, had made a similar experiment with a like result. From these observations, Lavoisier concluded that air consists of a mixture or compound of two gases, one capable of absorption by burning bodies, the other incapable of supporting combustion.

The results of these investigations, along with the observations of Scheele and Priestley, and a research on the combustion of organic substances made in 1777, the products of which he showed to be water and carbonic acid, enabled Lavoisier to enunciate his views

on combustion in a memoir published in 1778. The main points of this combustion or oxidation theory are as follows:

(1) Substances burn only in pure air ("air éminemment pur").

(2) This air is consumed in the combustion, and the increase in weight of the substance burnt is equivalent to the decrease in weight of the air.

(3) The combustible body is, as a rule, converted into an acid by its combination with the pure air, but the metals, on the other hand, into metallic "calces."

Hence the mechanism of combustion according to Lavoisier is represented by:

$$\underset{\text{(simple)}}{\text{Metal}} + \text{oxygen} = \underset{\text{(complex)}}{\text{metal "calx"}}$$

$$\text{Metal "calx"} - \text{oxygen} = \text{metal}$$

Carbon withdraws oxygen, forming fixed air

in direct contradiction to the phlogistic scheme:

$$\underset{\text{(complex)}}{\text{Metal}} - \text{phlogiston} = \underset{\text{(simple)}}{\text{metal "calx"}}$$

In 1783, there appeared a memoir by Lavoisier, entitled "Reflections concerning Phlogiston." After explaining the phenomena of combustion and reduction as combination with oxygen or its separation, he proclaimed the non-existence of phlogiston, saying in part as follows:

"But if in chemistry everything can be satisfactorily explained without the aid of phlogiston, it thereby becomes eminently probable that such a principle does not exist, that it is a hypothetical being, a gratuitous assumption, and sound logic is opposed to unnecessary complication. Perhaps I might have confined myself to these negative proofs and remained content to show that the phenomena can be better explained without phlogiston than by means of it; but the time has come when I must speak out in a more definite and formal manner concerning a view which I consider an error fatal to chemistry, and which appears to me to have considerably retarded progress by the method of false reasoning it has engendered. All these reflections prove what I have advanced, what it has been my object to demonstrate, what I will repeat once more, namely, that chemists have turned phlogiston into a vague principle, one not rigorously defined, and which consequently adapts itself to all the explanations for which it may be required. Sometimes this principle has weight and sometimes it has not; sometimes it is free fire and sometimes it is fire combined with the earthly element, sometimes it passes through the pores of vessels, sometimes these are impervious to it; it explains both causticity and non-causticity, transparency and opacity,

colors and their absence; it is a veritable Proteus, changing in form at each instant."

It was in this year that his important memoir upon the composition of water appeared, and it was this research which removed the last obstacles with which the antiphlogistic system had to contend.

James Watt, the Scotch inventor, was the first to state distinctly that water is not an element, but that it is composed, weight for weight, of two other substances, one of which he considered to be phlogiston and the other "dephlogisticated air"; and John Waltire, a friend of Priestley, was one of the first chemists to note the deposit of moisture on the inside of a tube after exploding a mixture of air and "inflammable gas." To Cavendish, however, belongs the credit of having first supplied the correct experimental basis upon which accurate knowledge could alone be founded. When Lavoisier learned that Cavendish had proved that water alone is produced by the combustion of hydrogen—information which was imparted to him by Sir Charles Blagden in 1782—he immediately repeated Cavendish's experiments on a large scale, and was assisted on that occasion by Laplace, Blagden also being present. A large quantity of water was produced, and the volumes of the combining gases were found to be 1 of oxygen to 1.91 of hydrogen. Not long after, in conjunction with Meunier, he performed the converse operation, in decomposing steam by conducting it over iron wire heated to redness in a porcelain tube. The iron removed the oxygen from the water, while the hydrogen passed on and was collected in the gas-holder.

The explanation of the solution of metals in acids was now simple: it depended on the decomposition of water. While the oxygen combined with the metal to form a "calx," the hydrogen was evolved; the "calx" dissolved in the acid, forming a salt of the metal. The operation of producing hydrogen by the action of steam on red-hot iron met with an equally easy explanation: the oxygen and iron united to form an oxide—the ancient "ethiops martial"—while the hydrogen escaped. The converse occurred during the reduction of a "calx" to the metallic state by hydrogen. In this case the hydrogen seized on the oxygen of the "calx," removed it in the form of water, and the metal was left. These experiments were due to Cavendish; all that Lavoisier did was to indicate and prove the true nature of the phenomena. The opponents of the new doctrines, Priestley prime among them, exerted themselves to disprove the view that water was a compound of oxygen and hydrogen. But their efforts were in vain. Many of Lavoisier's opponents had to admit the justice of his views; and chemists of standing commenced the application of his ideas, first in France (Berthollet 1786, de Morveau, and the cautious Fourcroy not until 1787), and soon in other countries also (Kirwan, *e.g.*, in 1792). Lavoisier's critical treatises, which were directed to showing

the untenability of the phlogistic theory, conjoined with his "Traité de Chimie," gave the final blow to that doctrine. The new doctrine was accepted by the most prominent chemists after the comparatively short time which was required to put it to the proof From the year 1792, after Klaproth, following Hermbstädt, Girtanner, etc., in Germany, Kirwan and Higgins in England, Troostwyk, Deiman and van Marum in Holland, and Giobert, Brugnatelli, etc., in Italy, had signified their adhesion to it, one may speak of the final victory of Lavoisier's system; and this, notwithstanding the fact that still many chemists of great eminence refused to accept it in its full extent—for example, de la Métherie, Sage and Baume in France; Westrumb, Gren, Crell, and Wiegleb in Germany; Gadolin and Retzius in Sweden; and Cavendish and Priestley in England.

Some opponents of the new system, mainly owing to their misinterpretation of the Lavoisierian views, continued to combat it till about 1800.

As late as 1796, Lamarck, for example, wrote an attack on the Lavoisierian theory of combustion, in which he referred to the "pretended existence of a material called oxygen which the pneumatic chemists have never seen nor studied, and the existence of which they imagine to explain the effects of 'fixed acidific air.'"

A few words should be said in this connection with regard to Lavoisier's views on the relation of plants and animals to the atmosphere.

Priestley already knew that oxygen was necessary for respiration, but his unfamiliarity with accurate analytical work and his close adherence to the phlogiston theory prevented him from arriving at a true explanation of the facts he observed. Lavoisier showed how oxygen was used up in the lungs, in the formation of carbonic acid and of water, and how this process, which he properly classed as one of combustion, furnishes to man the heat necessary for his existence. He demonstrated that the expired carbonic acid derives its carbon from the blood itself; that in the process of respiration we thus, to a certain extent, burn ourselves, and would consume ourselves if we did not replace, by means of our food, that which we have burned.

The experiments which Lavoisier made on respiration show the clearness of his methods.

One of Lavoisier's earlier memoirs, that presented to the Académie des Sciences in 1770, entitled "On the Nature of Water and on the Experiments adduced in Proof of the Possibility of its Change into Earth," illustrates his accuracy, thoroughness and acute reasoning. He states that the purpose of the research was as follows:

"I find myself confronted with the task of settling by decisive experiments a question of interest in physics, namely, whether water

can be changed into earth, as was thought by the old philosophers, and still is thought by some chemists of the day."

It had been noted by many earlier investigators, that when water was boiled for a long time in a glass vessel, a mass of white residue was found in the vessel after evaporation. This was long regarded as a conclusive proof that water could be changed into earth. Lavoisier weighed his glass vessel, and then, after heating water therein for one hundred days, found there was no change in the weight of the vessel and its contents. When he evaporated the water, he obtained a residue of earthy matter which he found corresponded, within the range of experimental error, with the loss in weight of the empty vessel. He therefore concluded from his experiments, "that the greater part, possibly the whole, of the earth separated from rain water by evaporation, is due to the solution of the vessels in which it has been collected and evaporated."

Scheele afterward showed that this "earth," or residue, possessed the same composition as the glass, thereby confirming Lavoisier's work. The old alchemical idea of transmutation was thus shown to be false, and was finally dismissed from chemistry.

Lavoisier established the important generalization that matter may be changed, but not destroyed nor created. The matter lost from the glass vessel was merely dissolved in the water. This is the principle of the Indestructibility of Matter, the fundamental principle of modern science. However, it must be realized that while from the commencement of his experimental life Lavoisier was guided in all his reasoning by the recognition of the principle of the conservation of mass, yet it was only after he had found this view proved by his work on combustion that he enunciated it (1785). To quote from his "Œuvres":

"Nothing is created, either in the operations of art or in those of nature, and it may be considered as a general principle that in every operation there exists an equal quantity of matter before and after the operation; that the quality and the quantity of the constituents is the same, and that what happens is only changes, modifications. It is on this principle that is founded all the art of performing chemical experiments; in all such must be assumed a true equality or equation between the constituents of the substances examined, and those resulting from their analysis."

The establishment of the law of the conservation of mass has followed curious lines. As Freund observes, Lavoisier did not arrive at it strictly inductively, by generalization from a large number of cases in which the weights of the substances participating in a chemical reaction were compared with the weights of those resulting from it. The available data of chemical investigations did not supply him with the material for so doing. The belief growing among

physicists of the imponderable nature of heat, together with the old view of the indestructibility of matter in general, must have supplied him with the basis for an assumption, from which he drew deductions that were verified by the result of experiment. Generally speaking, ever since his time, the scientific world has been content to regard the conservation of mass as an axiom.

A number of Lavoisier's statements indicate that his views upon the nature of his "matière de chaleur" (matter of heat) approximate to the Mechanical Theory of heat. Thus he states that "Heat is the energy which results from the imperceptible movements of the molecules of a substance; it is the sum of the products of the mass of each molecule into the square of its velocity."

According to him, matter consists of small particles which do not touch one another, since, otherwise, a diminution of volume by lowering of temperature could be explained: the matter of heat exists between these particles. The hotter a substance is the more of the matter of heat does it contain. In the investigations into the specific heats of various substances, carried out along with Laplace, Lavoisier further proved that, for a like increase in temperature, substances do not take up like quantities of the matter of heat. Lavoisier knew that, by the addition of heat, ice is first converted into water, and the water then into steam. Hence, gases contain most of the matter of heat. This is what we should understand when he says that his "air pur" consists of the acidifying principle and the matter of heat. During combustion the former unites with the combustible substance, and the matter of heat is liberated. It produces light and heat. Lavoisier also termed the matter of heat "calorique."

Lavoisier's views with respect to the heat liberated during combustion, altho not quite accurate, are also of great importance. He considered that when a solid substance (phosphorus) burned in gas (oxygen), and the product of the combustion was solid (phosphoric anhydride), the disengagement of heat was due to the condensation which the gas had undergone, in order that it may become solid. If the product was gaseous (carbonic anhydride), he attributed the disengagement of heat to the alteration of the specific heat. He advanced the general view that the heat of combustion must be greatest when two gases unite to form a solid substance. How correctly he understood the application of these fundamental ideas is shown by his mode of explaining the lowering of temperature produced by dissolving salts in water. Lavoisier assumed, as we do, that it is the change of state of aggregation which occasions the absorption of heat. He showed, further, that the evolution of heat which occurs on mixing sulphuric acid with water is accompanied by a decrease in volume, and that both maxima coincide; so that theory and experiment agree

It may be said, therefore, that Lavoisier laid the foundation for the modern thermo-chemistry.

Lavoisier also occupied himself with organic chemistry, or the chemistry of life-products, and made a beginning toward a scientfic study of it by devising a method of analysis by which these bodies could be burned, and the water and carbon dioxide which were formed measured.

He heated a known weight of the substance with a known weight of red mercury oxide, and weighed the carbonic acid and water produced. He knew the oxygen content of the mercuric oxide, and so could ascertain how far this supplied the carbon and hydrogen with the oxygen they required, and how far this was furnished by the compound under investigation. Lavoisier in this way determined the composition of alcohol.

However, the whole system of quantitative organic chemistry was too young for Lavoisier to anticipate the nicety with which Liebig, later, could handle these methods of ultimate analysis; he considered his experiments to be merely confirmatory of his system, the composition of sugar a mere incident. Organic bodies in general he regarded as oxides of a radical, which might itself contain hydrogen and carbon, or in some cases these together with nitrogen, sulphur, and phosphorus.

Lavoisier adhered to Boyle's definition of an element. With him, an element was any substance which could not be further decomposed. The metals and the most important non-metals were ranked among the elements; and compound bodies like the alkalies, ammonia and the earths were numbered among these also, but not without considerable uncertainty being expressed as to their elementary nature. Oxygen, also recognized as an element, became, because of its part in combustion and its capacity for combining with so many other elements, the center point of the antiphlogistic system, which indeed owed its inception to the knowledge of the behavior of other elements toward oxygen. The importance which Lavoisier attached to this gas is clearly shown in his theory of acids, in which he explained the properties of acids by the hypothesis of the acidifying principle being oxygen, the name of which (οξυγενναω, I generate acid), still bears witness to this view; and in the statement that the bases which combine with acids also contain oxygen. The composition of a large number of compounds—oxides, acids and salts—was thus rightly interpreted, the phlogistic hypothesis having regarded as simple the substances belonging to the first two of these classes.

The views of Lavoisier and his disciples with respect to elements and compounds are to be found in the treatise entitled "Methode de nomenclature chimique," which was published by Lavoisier conjointly with Guyton de Morveau, Berthollet, and Fourcroy, in 1787. This

work, in conjunction with the "Traité Elémentaire de Chimie" (1789), changed the existing language of chemistry and shaped the course of progress still pursued.

In the first-mentioned treatise all substances are divided into elements and compounds. To the former belonged—in addition to light and heat—oxygen, hydrogen and nitrogen; these formed the first class. The second group contained the acid-forming elements, sulphur, phosphorus and carbon, to which were added the hypothetical radicals of hydrochloric, hydrofluoric and boracic acids. The third class comprised the metals, the fourth the earths, and the fifth the alkalies; but Lavoisier considered the elementary nature of the last of these as so improbable that in the "Traité Elémentaire de Chimie" he no longer included them among the elements. For the nomenclature of the latter, the old names of the metals and of some of the non-metals (*e.g.*, soufre, phosphore, etc.) were retained, while Lavoisier's new names for others of the non-metallic elements (*e.g.*, oxygène, hydrogène, azote) were introduced.

Next came the binary substances, consisting, as they did, of two elements. The acids occurred in this class. Their names were in each case composed of two words, of which the first was common to them all and indicated their acid character (acide), while the second was a specific name indicating the element or radical occurring in each. Thus we have "acides sulfurique, carbonique, phosphorique, nitrique," etc. Two acids containing the same element or radical were distinguished by the different termination of the specific name; that containing the smaller proportion of oxygen receiving the termination "eux," whereby such names as "acides sulfureux, nitreux," etc., were obtained. Hydrochloric acid was called "acide muriatique," and the existence of oxygen in it was assumed; while oxygen was supposed to be present in still greater quantity in chlorine—the "acide muriatique oxygène."

The names of the binary substances of the second group—*i.e.*, of the basic compounds containing oxygen—were formed in a manner exactly similar. For these the general designation "oxides" was introduced, and to this word the specific name was appended in the genitive; for example, "oxide de zinc," "oxide de plomb," etc.

The remaining binary compounds were distinguished as sulphur, phosphorus, carbon, etc., compounds, and received the class names "sulfures," "phosphures," "carbures," etc.

Compounds of the metals with one another were called "alliages" (alloys), the expression "amalgames" being retained, however, for mercury alloys.

With regard to the ternary compounds, the salts alone need be mentioned. They obtained their class names from the acids from

which they were derived, and were called accordingly "sulfates," "nitrates," "phosphates." The termination "ate" became "ite" when the salts were derived from the acid poorer in oxygen instead of from that richer in oxygen. The name of the base was appended; for example, sulfate de zinc, de baryte, etc.

This system of nomenclature embodies the principles and constitutes the basis of the chemical nomenclature now in use.

Studies of the new nomenclature were published by Scherer (1792), who made an attempt to Germanize the new terms; Eimbke (1793), who sought to reconcile the old and the new views in his synonymicon; Arzt (1795); Spalding, who published a work at Hanover, N. H., in 1799, in which he followed de Morveau, but adopted the name "septon" for nitrogen and "septic acid" for nitric acid, as proposed by Samuel Mitchell, of New York; Sevrin (1807); and Ritter (1808). It is amusing to note here that Richard Chenevix, a London chemist, published a critical examination of the nomenclature of the "French Neologists" in 1802, in which he quoted Balthazar Sage's remark that oxygen signified the "son of a vinegar merchant."

When the nature of the theoretical views held during the Phlogistic Period is compared with that of the ones accepted at the time of Lavoisier's execution, it will be understood why a new era—that of quantitative chemistry, or, as Fourcroy termed it, the "French Chemistry"—dates from him.

As mentioned, the teachings of Lavoisier gradually became recognized in France—a reward which Lavoisier himself had the satisfaction of witnessing—and also gained ground in England, and, through the influence of Klaproth, in Germany, where his works were translated, so that at the beginning of the nineteenth century chemists had almost universally given in their adherence to the antiphlogistic chemistry.

Lavoisier not only overthrew the old theory, but it is to his credit that he introduced a new one in its place, and it is perhaps advisable to state here the most important heads of his theory (Ladenburg):

1. In all chemical reactions it is the kind of matter alone that is changed, while its quantity remains constant; consequently, the substances employed and the products obtained may be represented by an algebraic equation in which, if there is any unknown term, this may be calculated.

2. In the process of combustion the burning substance unites with oxygen, whereby an acid is usually produced. In the combustion of the metals, metallic calces are produced.

3. All acids contain oxygen, united, as he expresses it, with a basis or radical which, in inorganic substances, is usually an element, but in organic substances is composed of carbon and hydrogen, and frequently contains also nitrogen or phosphorus.

If these three statements be contrasted with the views of the phlogistians—*i.e.*, with the theories which prevailed prior to Lavoisier—we shall appreciate the reformation introduced by him into chemical science. The direction of chemical thought was entirely changed, and the facts hitherto ascertained appeared in a new light.

Chemistry now had the basis of a correct theory; and what was of greater value, a knowledge that theories could be deduced only from the weight relations of actually occurring reactions. To quote Venable, "There were to be no baseless and delusive dreams for the future, altho mistakes might be made in the interpretation of facts. Further, the grand division into elements and compounds had been effected, and a suitable nomenclature had been devised, capable of any expansion demanded by increase of knowledge. The balance, too, had been introduced as the instrument by which precision and accuracy were to be attained, and the great arbiter of the fate of theories. True progress now became possible; and the century which has since passed has seen this science develop and grow, until men have come scarcely to dare to put a limit to its possibilities."

Those three investigators—Guyton de Morveau, Claude Louis Berthollet, and Antoine François Fourcroy—who, in conjunction with Lavoisier, furnished the basis of a scientific nomenclature, and also contributed to the development of chemistry by their other works, are next to be considered.

Louis Bernard Guyton de Morveau (1737-1816) was a zealous propagandist of the new chemistry, and, upon his election as a deputy in 1791, he endeavored to render the chemical knowledge he had acquired and its practical application of assistance to France. He aided in founding the "Ecole Polytechnique," in which institution he subsequently accepted a professorship, and with Maret and Durande as co-authors, he published a comprehensive text-book on chemistry in three volumes, entitled "Elémens de Chymie théorique et partique" (1777).

Claude Louis Berthollet, who was born at Talloire in Savoy in 1748, was one of the most distinguished of the many contemporaries and successors of Lavoisier. He became an antiphlogistonist in 1786, and from that time until his death in 1822 he conducted valuable chemical researches. His important experimental investigations were in connection with the composition of ammonia, the properties and nature of chlorine, the production of bleaching compounds from chlorine, and the composition of hydrogen sulphide and hydrocyanic acid. He observed that solutions of chlorine in water gave off bubbles of oxygen, when exposed to the action of light, while hydrochloric acid remained. Lavoisier had considered that this acid was a compound of the radical "murium" with oxygen, and consequently Berthollet explained the

phenomenon referred to by regarding chlorine as "oxymuriatic acid"—that is, a higher oxygenated product of "murium." Berthollet discovered that ammonia is composed of hydrogen and nitrogen; and, after convincing himself that hydrogen sulphide and hydrocyanic acid contained no oxygen, he opposed the dictum that oxygen was the principle of acidity.

Berthollet was the author of the following works: "Elémens de l'art de la Teinture" (1791), "Recherches sur les Lois de l'Affinité" (1801), and "Essai de Statique Chimique" (1803). The last-mentioned treatise was an exceedingly important contribution to theoretical chemistry, for it exerted a powerful influence on the question of chemical affinity. Berthollet's doctrine of affinity will be discussed in the next chapter.

Antoine François de Fourcroy (1755-1809) deserves mention as an organizer, author and teacher. He was an active expounder of the antiphlogistic doctrine, and propagated the new chemistry by means of articles and treatises. He was the author of the following works: "Leçons Elémentaires d'Historie Naturelle et de Chimie" (1782), "Elémens d'Histoire Naturelle et de Chimie" (1789), "Mémoires et Observations de Chimie" (1784), "Philosophie Chimique" (1792), and "Système des Connaissances Chimiques et leurs Applications aux Phénomènes de la Nature et de l'Art" (1801). Fourcroy's experimental work served to pave the way for biological chemistry, and his joint investigations with Vauquelin furthered the knowledge of organic compounds.

Another important representative of chemistry in France at this time was Louis Nicholas Vauquelin (1763-1829), who succeeded Fourcroy as Professor of Chemistry to the Medical Faculty in 1809. To Vauquelin is owed the discovery of chromium (1797) and beryllia (1797), the former of which he found in lead spar and the latter in beryl. His work on the separation of platinum, palladium (discovered by Wollaston in 1803), rhodium (Wollaston, 1804), iridium (Tennant, 1803), and osmium (Tennant, 1803), is also worthy of note. Vauquelin's investigations on the metals of the platinum group were carried out with the assistance of Fourcroy, and it is likely that they preceded Smithson Tennant in the discovery of iridium. In his researches in organic chemistry, Vauquelin discovered quinic acid, asparagine, and camphoric acid. He was the author of two works—"Instruction sur la Combustion des Vegetaux, la Fabrication du Salin, de la Cendre Gravelee" (1794), and "Manuel de l'Essayeur" (1812)—both of which passed through several editions.

The leading chemists of Great Britain and Sweden at the time when Lavoisier began his attack on the phlogistic theory strongly opposed

the new chemistry. Cavendish, Priestley, Bergman, and Scheele were unable to accept it, but Black renounced the old doctrine in 1791, and was followed by Dickson and Richard Kirwan. The latter's interesting "Essay on Phlogiston and the Constitution of Acids" (1787) deals with the transition period from the old to the new theories, and was translated into French by Mme. Lavoisier. Among the lesser celebreties in the science in England, Lubbock subscribed himself to Lavoisier's views as early as 1784, while Peart and Pew attempted to prove the existence of phlogiston as late as 1795.

In 1810, a small "Essay on Combustion" was published in Philadelphia by a Mrs. Fulhame, "wherein the phlogistic and antiphlogistic hypotheses are proved erroneous." This is merely mentioned on account of its being one of the earliest American contributions to the subject.

Martin Heinrich Klaproth (1743-1817), first Professor of Chemistry at the University of Berlin, was characterized by the accuracy with which he carried out his investigations; the quantitative method of research was developed and improved by him, and he thereby helped on the recognition of the cardinal principles advocated by Lavoisier. After Klaproth had become satisfied with the correctness of the antiphlogistic doctrine, by testing the reactions which took place in combustion and calcination, he became one of its devoted adherents; and his example led many other German chemists in the same direction.

Klaproth discovered uranium (1789), titanium (1794), cerium (1803), and zirconia (1789); and investigated the new elements chromium, beryllium, and tellurium (discovered by Müller von Reichenstein in 1782). He was particularly active in analytical and mineralogical chemistry, and introduced many improvements of analytical methods. Klaproth was, in fact, a true investigator in every sense of the word. In reporting the results of an analysis, he published the actual figures obtained, thus introducing a new custom which made it possible to subject results to correction or criticism. His works are "Chemische Untersuchung der Mineralquellen zu Karlsbad" (1790), and Beiträge zur chemischen Kenntniss der Mineralkörper" (1795-1815). The latter is a collection of his papers published in the "Memoirs" of the Berlin Academy and in the "Chemische Annalen für die Freunde der Naturlehre." He also published the "Chemisches Wörterbuch" (1807-10, 5 volumes; 1815-19, 4 volumes), a French edition of which appeared in 1811; and edited the third edition of Friedrich Gren's "Systematisches Handbuch der Gesammten Chemie," an excellent treatise first published in 1787-90.

From 1803-10, Klaproth was on the board of editors of the "Neues allgemeines Journal der Chemie," which was started in 1798 by

Scherer. In this connection it should be mentioned that at that time about twelve chemical periodicals were being published in Germany, three in France, two in Italy, two in Belgium, one each in Holland and Sweden, and two in England. These journals exercised the greatest influence upon the enlargement and diffusion of chemical knowledge, and they show the extent to which chemistry was fostered during the last decades of the eighteenth century.

CHAPTER X

THE ATOMIC THEORY AND THE WORK OF DAVY

A DESIRE ingenite in the human mind to find an explanation of natural phenomena, by the aid of speculations respecting the ultimate constituents of matter, resulted in guesses and ideas concerning atoms, in olden times, without, however, the evolution of an exact chemical atomic theory. With respect to the hypotheses of the ancient philosophers regarding the constitution of matter, the following estimate by Clifford will suffice in this connection:

"From the earliest times that men began to form any coherent idea of [the world] at all, they began to guess in some way or other how it was that it all began, and how it was all going to end. . . . Modern speculations are attempts to find out how things began and how they are to end, by consideration of the way in which they are going on now. . . . A great number of people appear to have been led to the conclusion that [the modern theory of the molecular constitution of matter] is very similar to the guesses which we find in ancient writers—Democritus and Lucretius. . . . It so happens that these ancient writers did hold a view of the constitution of things which in many striking respects agrees with the view which we hold in modern times. . . . The difference between the [ancient and modern views] is mainly this: the atomic theory of Democritus was a guess, and no more than a guess. Everybody around him was guessing about the origin of things, and they guessed in a great number of ways; but he happened to make a guess which was more near the right thing than any of the others."

The conception of atoms had up to the close of the eighteenth century been almost entirely the property of the metaphysician and the mathematical physicist, and had assisted in extending their sciences. With the exception of Sennert and Boyle, chemists had aided little in its formulation and less in its establishment, nor had they derived inspiration from it for the proper founding of their own science. For more than a century they had been following the "ignis fatuus" of a false theory of combustion and a most elusive hypothetical phlogiston. The close of the eighteenth century found them engaged in bitter strife over these theories, and too fully occupied to think of much else than the destruction of the old beliefs and the adaptation of the new.

The master mind of Lavoisier, who had wrought this revolution, was busied with the greater work of reconstruction and, dealing little with hypotheses which could not be directly proved by experiments in his laboratory, was laying broad and strong the foundations of the New Chemistry. Consequently the works of Bergman, Scheele, Priestley, Black, Cavendish, Macquer, and others do not treat of atoms and their moving forces, except in an occasional indefinite reference to some sort of particle.

Yet the chemist was the very one required to undertake the scientific development of the atomic hypothesis and to establish it as a theory, by discovering a series of facts which were connected together by it and found in it a simple explanation.

In 1783, the English chemist Kirwan went so far as to refer to affinity as that force which holds atoms so intimately together that simple mechanical means are insufficient to separate them; while his countryman, Higgins, writing in 1790 on the composition of sulphurous and sulphuric acids, expressed the opinion that the atom of sulphur is combined with one atom of oxygen in the first, but with two atoms in the second. It is in view of this statement, and others similar to it, that some have regarded Higgins as the real originator of the modern atomic doctrine. However, Higgins restricted his attention to a small number of compounds. His conceptions were not consistent with fact; he regarded those weights of elements which combine to form the simplest compound as in general equal; and he made no attempt to seek confirmation for any theory he had in the laboratory. For long the common consent of public opinion has given the undivided honor, due to the discoverer of the great atomic generalization in its modern aspect, to John Dalton.

Before the establishment of the chemical atomic theory could be brought to completion, however, it became necessary to fix the signification of the term "chemical proportions," according to which simple substances unite to form compound bodies; and an important part of this question was solved by two chemists prior to Dalton—Richter and Proust.

Jeremias Benjamin Richter (1762-1807) published in his "De usu Mathesos in Chymia" (1789), "Aufangsgründe der Stöchyometrie oder Messkunst Chymischer Elemente" (1742-1794), and "Ueber die neuren Gegenstände der Chymie" (1791-1802), the results of researches made mainly while employed as a works chemist in Berlin. The last two mentioned treatises contain the conclusions which he drew from his work upon the proportions by weight in various compounds.

Richter looked upon chemistry as a branch of applied mathematics, and exhibited all the distressing qualities of a person possessed by a fixed idea; he spent his life in seeking arithmetical regularities in the

weights of acids and alkalies neutralizing each other, and in finding them in spite of their non-existence.

Nevertheless, he managed to make discoveries of the highest importance. He not only noticed, but also correctly interpreted the fact, that when two neutral salts decompose one another, the resulting salts are still neutral. To quote his conclusions: ". . . concerning that very common experience that two neutral salts on decomposition again produce neutral compounds, I could draw no direct inference other than that fixed quantitative relations must exist between the constituents of the neutral salts. If a solution of two components is so constituted that neither of them, as long as it remains in the solution, exhibits the peculiar characteristics it had before solution—*e.g.*, the reactions of an acid or of an alkali—then such a solution is called saturated or neutral, or also a neutral compound. . . . When two neutral solutions are mixed and a decomposition ensues, the newly formed products are also, almost without exception, neutral. . . . Hence it follows that if the combining ratios in the original compounds be known, those in the newly formed compounds are known also."

C. F. Wenzel (1740-1793), at an earlier date (1777), had demonstrated that acids and bases combine in constant proportions, but had failed to note the persistency of the neutrality in the double decomposition of the neutral salts.

Richter deduced from the maintenance of neutrality when one metal precipitates another from a neutral solution—a relation Bergman had observed, but which he interpreted in terms of another theory—that the quantities of two metals which dissolve in the same amount of acid also unite in their oxides with the same amount of oxygen. Therefore, he established that quantities of two substances which are equivalent in one reaction are also equivalent in others; he was the originator of stoichiometry, or "the art of chemical measurement, which has to deal with the laws according to which substances unite to form chemical compounds."

Notwithstanding the fact that Richter's treatise contained such important discoveries these remained unrecognized until Fischer published a table of the relative affinities of bases and acids, founded on the values Richter had obtained, in his translation of Berthollet's "Recherches," made in 1802.

Berthollet accepted the law of proportionality and gave an account of it in his "Essai de Statique Chimique," in which he reprinted Fischer's note. Thus Richter's work, which at the time of its publication had been almost completely ignored, became more widely known and appreciated.

Louis José Proust (1755-1826), altho a Frenchman by birth, conducted his most important researches in Madrid, where he settled after 1791. The work for which he is celebrated was the result of a series of questions which Berthollet had advanced.

The two works of Berthollet on affinity—"Recherches sur les Lois de l'Affinité" and "Essai d'une Statique Chimique"—were particularly directed against false views of affinity and the misuse of the so-called affinity tables of Geoffroy, Bergman, and others.

He contended that affinity was by no means a simple force, and easy to determine or measure; but was influenced by temperature, physical state, cohesion, and especially by mass. The latter largely determined the course of chemical reactions.

He went further, however, and from the correct premise of the influence of mass on the chemical effect produced, Berthollet drew the erroneous inference that mass had an influence, not only on the amount of change but also on the kind, producing a continuous variation in the ratio in which the constituents are united in the compound. He asserted the variability of the composition of chemical compounds, the possibility of combination between constituents in all sorts of continuously varying ratios. None of the other leading chemists of the day were able to concur with his views as to the lack of any fixity or constancy of proportions in chemical compounds. Yet they raised no objection, probably owing to Berthollet's reputation, and it remained for Proust to attack the theoretical conclusions of his eminent contemporary.

Proust's numerous papers in his controversy with Berthollet appeared in the "Journal de Physique" between the years 1802 and 1808. The lucidity of the arguments employed, the variety of the experimental work described, and the freedom and keenness of the style, render these papers, which deal exclusively with the distinctly dry subject of quantitative analysis, most interesting reading even now.

Proust proves that substances formed under the most varied conditions have a fixed composition, and he shows that Berthollet's examples of variable composition were all cases of mixtures. This involves him in the necessity of discriminating between mixtures and compounds, an undertaking the difficulties of which he fully realized, and with which he dealt in a manner very much like that still resorted to for the same purpose.

In 1799, Proust had proved the constant composition of native and artificial carbonate of copper, and had enunciated the general principle of which this constituted an example. Of greater importance than these were observations he made upon the two compounds iron forms with sulphur and the two stages of oxidation shown by tin. He further investigated the compounds of antimony, cobalt, nickel, and copper, and throughout he found that, vary the conditions and relative

masses at pleasure, the oxides and sulphides produced always have a definite composition. To be sure, an element might combine with oxygen or sulphur in two proportions, but each was a compound of definite proportions.

Proust showed the error which underlay the old method of determining the quantity of oxygen in oxides, of estimating the metal and calculating the oxygen by difference, proving that in many cases the bodies so examined were not oxides at all, but compounds containing hydrogen—hydroxides we now call them. He, moreover, demonstrated that many of the bodies, on the analysis of which Berthollet had based his generalization, were not simple at all, but mixtures of substances, themselves of perfectly definite composition. So accurate were his analytical investigations, and so logical his reasoning, that Berthollet was overcome at every point. The law of definite chemical proportions, as we now have it, was the fruit of his persevering labors. This law is one of the fundamental principles of chemistry. It is expressed by the greatest teacher of chemistry as follows:

"If one substance is transformed into another, then the masses of these two substances always bear a fixed ratio to each other. If several substances react together, then their masses, as well as those of the new bodies formed, always bear fixed proportions to each other." (Ostwald, "Outlines of General Chemistry.")

Undoubtedly, if Proust had calculated the results of his experiments on the composition of binary compounds (sulphides, oxides) in another manner from what he did, he would have discovered the law of multiple proportions, but the propounding of this is due to Dalton.

John Dalton (1766-1844) was born at Eaglesfield, in Cumberland, the son of a poor weaver; endowed with natural aptitude and an indomitable will, he utilized all possible opportunities for the study of mathematics and natural philosophy. From 1781 to 1793 he taught school, instructed and lectured at Kendal, devoting all the time and energy he could spare to scientific investigations, chiefly meteorological.

In 1793 he went to Manchester as tutor of mathematics and natural philosophy at a Presbyterian College. Tho he resigned this post six years later, he remained in Manchester to the end of his life, earning his living as a private teacher, and devoting himself uninterruptedly and earnestly to scientific research.

The earlier researches of Dalton on the expansion of gases by heat and their absorption by liquids were of considerable influence on his later chemical work, as it was through them that he acquired the experimental skill which led to the discovery of the law of multiple proportions, which, with the conception of the atomic theory which arose from it, dates from 1802.

On November 12, 1802, Dalton read a paper entitled "An Experi-

mental Enquiry into the Properties of the Several Gases or Elastic Fluids constituting the Atmosphere," in which is found the first example of the law. In determining the amount of oxygen in the air the following experiment was performed:

"If 100 measures of common air be put to 36 of pure nitrous gas in a tube 3/16 of an inch wide and 5 inches long, after a few minutes the whole will be reduced to 79 or 80 measures, and exhibit no signs of either oxygenous or nitrous gas. If 100 measures of common air be admitted to 72 of nitrous gas in a wide vessel over water, such as to form a thin stratum of air, and an immediate momentary agitation be used, there will, as before, be found 79 or 80 measures of pure azotic gas [nitrogen] for a residuum. If, in the last experiment, less than 72 measures of nitrous gas be used, there will be a residuum containing oxygenous gas; if more, then some residuary nitrous gas will be found. These facts clearly point out the theory of the process: the elements of oxygen may combine with a certain portion of nitrous gas, or with twice that portion, but with no intermediate quantity. In the former case nitric acid is the result; in the latter nitrous acid: but as both these may be formed at the same time, one part of the oxygen going to one of nitrous gas, and another to two, the quantity of nitrous gas absorbed should be variable; from 36 to 72 per cent. for common air."

With regard to this experiment Roscoe says: "In the memorable case in which Dalton announces the first instance of combination in multiple proportions the whole conclusion is based upon an erroneous experimental basis. If we repeat the experiment, as described by Dalton, we do not obtain the results he arrived at. We see that Dalton's conclusions were correct, altho in this case it appears to have been a mere chance that his experimental results rendered such a conclusion possible."

Chemistry continued in next volume.